ATS- 16651

Department of Geodetic Science

BASIC RESEARCH AND DATA ANALYSIS FOR THE NATIONAL GEODETIC SATELLITE PROGRAM AND FOR THE EARTH AND OCEAN PHYSICS APPLICATIONS PROGRAM

Thirteenth Semiannual Status Report
Research Grant No. NGL 36-008-093
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and

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The Ohio State University
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Columbus, Ohio 43212
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PREFACE

These projects are under the supervision of Professor Ivan I. Mueller, Department of Geodetic Science, The Ohio State University, and the technical direction of Mr. James P. Murphy, Special Programs, Office of Applications, Code ES, NASA Headquarters, Washington, D. C. The contracts are administered by the Office of University Affairs, NASA, Washington, D. C. 20546.

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1. STATEMENT OF WORK

The statement of work for this project includes data analysis and supporting research in connection with the following broad objectives:

(1) Provide a precise and accurate geometric description of the earth's surface.

(2) Provide a precise and accurate mathematical description of the earth's gravitational field.

(3) Determine time variations of the geometry of the ocean surface, the solid earth, the gravity field and other geophysical parameters.

2. ACTIVITIES RELATED TO THE NGSP
(Grant No. NGL 36-008-093)

2.1 Data Acquisition

During this reporting period the following data in respect of latest solutions from National Geodetic Survey, Goddard Space Flight Center and Smithsonian Astrophysical Observatory were received:

2.11 BC-4 World Net

Complete three-dimensional coordinates with their standard deviations were extracted as under, with regard to National Geodetic Survey's BC-4 World Net from Dr. H. H. Schmid:

- 3-dimensional Cartesian Coordinates of 45 stations with their standard deviations of NGS-Geometric Solution (Table 2.1-1).
- 3-dimensional Cartesian Coordinates of 45 stations with their standard deviations of NGS-Combined (with Doppler) Final Solution (Table 2.1-2).

It is important to note that the y-axis is positive towards 90° West Longitude in the above sets of coordinates.

2.12 GEM 6 World Net

A set of ellipsoidal coordinates for Solution GEM 6 was obtained from the contribution of NASA/GSFC section of NGSP Report (Table 2.1-3).

As confirmed on phone by Mr. J. Reece, the sigmas given are in meters for each of the three rectangular components.

2.13 Standard Earth III

A set of three dimensional coordinates with respect to final solution of Standard Earth III was received from the Smithsonian Astrophysical Observatory (Table 2.1-4).

Table 2.1-1

NGS Three-dimensional Cartesian coordinates

No.	Station Name	X (m)	σ_X ± (m)	Y (m)	σ_Y ± (m)	Z (m)	σ_Z ± (m)
1	Thule	546567.862	2.297	1389990.609	3.447	6180239.602	3.960
2	Beltsville	1130761.500	0	4830828.597	0	3994704.584	0
3	Moses Lake	-2127833.613	.790	3785861.054	2.976	4656034.740	2.906
4	Shemya	-3851782.861	4.888	-396404.016	5.654	5051347.586	6.673
6	Tromso	2102925.118	3.663	-721667.562	4.772	5958188.868	4.748
7	Azores	4433636.070	4.737	2268143.467	4.362	3971656.223	4.945
8	Surinam	3623227.823	4.563	5214231.698	4.502	601551.302	5.716
9	Quito	1280815.597	4.338	6250955.436	5.800	-10793.013	5.717
11	Maui	-5466020.732	5.045	2404435.198	4.352	2242229.885	4.703
12	Wake	-5858543.398	5.308	-1394489.166	5.281	2093807.584	5.391
13	Kanoya	-3565865.509	5.200	-4120692.866	6.694	3303428.249	6.131
15	Mashhad	2604346.389	3.988	-4444141.147	5.513	3750323.381	4.974
16	Catania	4896383.234	4.080	-1316167.822	4.463	3856673.791	4.698
19	Dolores	2280603.832	4.190	4914545.588	4.789	-3355412.286	6.839
20	Easter	-1888616.886	4.845	5354892.780	6.246	-2895739.444	7.217
22	Pago Pago	-6099954.446	5.392	997367.321	4.710	-1568567.088	5.883
23	Thursday Is.	-4955371.694	4.671	-3842221.799	5.689	-1163828.451	5.852
31	Invercargill	-4313815.856	4.687	-891322.098	5.238	-4597238.676	6.398
32	Perth	-2375397.874	4.579	-4875524.035	5.746	-3345372.936	6.170
38	Revilla	-2160983.561	2.008	5642711.612	3.653	2035371.417	4.062
39	Pitcairn	-3724766.403	6.502	4421236.249	6.480	-2686072.609	7.288
40	Cocos	-741969.205	4.859	-6190770.789	6.606	-1338530.638	5.843
42	Addis Ababa	4900734.926	4.844	-3968226.427	5.481	966347.675	5.103
43	Sombrero	1371358.188	4.171	3614760.271	4.969	-5055928.396	8.156
44	Heard	1098896.432	6.448	-3684591.597	7.801	-5071838.356	9.919
45	Mauritius	3223422.870	4.472	-5045312.452	6.019	-2191780.736	6.065
47	Zamboanga	-3361946.845	4.909	-5365778.338	6.501	763644.128	6.121
50	Palmer	1192659.730	5.174	2450995.361	7.275	-5747040.896	10.171
51	Mawson	1111335.585	5.189	-2169243.189	5.456	-5874307.692	8.002
52	Wilkes	-902598.435	4.912	-2409507.607	5.700	-5816527.805	7.901
53	McMurdo	-1310841.759	4.993	-311248.105	5.500	-6213251.231	7.886
55	Ascension	6118325.238	5.260	1571746.070	4.816	-878595.457	5.507
59	Christmas	-5885331.078	5.213	2448376.867	4.435	221683.837	5.446
60	Culgoora	-4751637.577	4.552	-2792039.266	5.653	-3200142.319	5.866
61	So. Georgia	2999903.036	4.896	2219368.228	6.055	-5155246.454	8.547
63	Dakar	5884457.561	4.898	1853492.773	4.257	1612863.206	5.072
64	Chad	6023375.533	4.690	-1617924.383	4.242	1331742.422	4.834
65	Hohenpeissenberg	4213552.554	3.7[illegible]	-820823.968	4.444	4702787.513	4.620
67	Natal	5186398.560	5.260	3653936.203	4.854	-654277.651	5.569
68	Johannesburg	5084812.984	5.229	-2670319.559	5.065	-2768065.639	6.585
69	De Cunha	4978412.958	8.167	1086867.619	6.918	-3823159.761	9.443
72	Thailand	-941692.348	5.593	-5967416.884	6.919	2039317.530	5.461
73	Chagos	1905130.320	4.345	-6032252.624	6.702	-810711.562	5.751
75	Mahe	3602810.169	4.910	-5238217.287	6.393	-515928.653	5.650
111	Wrightwood	-2448854.721	2.088	4667988.213	3.367	3582758.969	3.185

Table 2.1-2-

NGS Three-dimensional Cartesian coordinates from Combined Final Solution

No.	Station Name	X (m)	σ_X ± (m)	Y (m)	σ_Y ± (m)	Z (m)	σ_Z ± (m)
1	Thule	546588.043	2.524	1389976.770	2.442	6180221.157	3.191
2	Beltsville	1130783.206	2.464	4830812.170	2.853	3994691.260	2.979
3	Moses Lake	-2127810.402	2.337	3785844.188	2.610	4656021.673	2.896
4	Shemya	-3851759.714	3.610	-396416.742	3.622	5051324.861	4.235
6	Tromso	2102943.362	2.365	-721679.260	2.697	5958170.871	3.090
7	Azores	4433652.575	3.091	2268128.968	2.686	3971641.629	3.327
8	Surinam	3623251.037	3.166	5214216.431	3.288	601536.293	3.489
9	Quito	1280842.366	3.158	6250939.190	3.947	-10807.932	3.487
11	Maui	-5466002.263	3.288	2404414.762	2.767	2242214.785	3.235
12	Wake	-5858531.333	3.287	-1394513.654	2.966	2093798.651	3.211
13	Kanoya	-3565848.055	3.138	-4120713.101	3.636	3303409.134	3.581
15	Mashhad	2604363.535	2.345	-4444158.701	2.711	3750306.588	2.712
16	Catania	4896401.374	2.357	-1316181.910	2.316	3856657.080	2.572
19	Dolores	2280628.090	2.674	4914528.492	2.950	-3355416.607	3.163
20	Easter	-1888587.555	3.790	5354875.392	3.952	-2895751.980	3.784
22	Pago Pago	-6099939.342	3.122	997345.983	2.730	-1568582.700	3.208
23	Thursday Is.	-4955355.561	2.613	-3842245.988	2.427	-1163843.516	2.534
31	Invercargill	-4313799.508	2.680	-891345.724	2.588	-4597253.294	2.833
32	Perth	-2375382.732	2.505	-4875545.638	2.621	-3345387.849	2.728
38	Revilla	-2160960.225	2.510	5642694.520	3.078	2035358.416	3.176
39	Pitcairn	-3724745.647	6.280	4421218.035	5.694	-2686087.346	5.255
40	Cocos	-741953.040	3.161	-6190790.099	3.069	-1338547.676	2.752
42	Addis Ababa	4900753.422	2.762	-3968244.643	2.626	966329.417	2.552
43	Sombrero	1371383.334	2.724	3614745.095	3.157	-5055927.530	3.641
44	Heard	1098912.818	5.747	-3684612.693	6.212	-5071853.727	7.780
45.	Mauritius	3223440.444	2.656	-5045332.006	2.739	-2191798.454	2.698
47	Zamboanga	-3361931.463	2.812	-5365800.248	3.094	763627.375	3.330
50	Palmer	1192684.033	3.433	2450986.983	4.323	-5747037.701	4.672
51	Mawson	1111352.024	4.285	-2169264.675	3.238	-5874322.862	4.844
52	Wilkes	-902583.987	3.525	-2409530.660	3.232	-5816542.503	4.730
53	McMurdo	-1310828.143	3.356	-311271.145	3.073	-6213265.956	3.958
55	Ascension	6118342.544	3.108	1571732.245	2.883	-878608.379	3.089
59	Christmas	-5885315.086	3.027	2448357.151	2.732	221669.643	3.145
60	Culgoora	-4751621.039	2.483	-2792063.383	2.372	-3200156.628	2.442
61	So. Georgia	2999924.593	3.745	2219357.041	4.232	-5155247.563	4.886
63	Dakar	5884475.772	2.853	1853478.486	2.307	1612848.261	2.930
64	Chad	6023393.960	2.749	-1617940.871	2.236	1331726.674	2.508
65	Hohenpeissenberg	4213570.222	2.356	-820837.313	2.346	4702769.262	2.758
67	Natal	5186415.778	3.301	3653921.575	3.208	-654288.938	3.072
68	Johannesburg	5084832.837	3.146	-2670338.698	2.580	-2768083.655	3.248
69	Da Cunha	4978430.027	7.231	1086856.181	5.644	-3823164.893	7.581
72	Thailand	-941678.219	3.661	-5967438.461	3.337	2039300.514	2.969
73	Chagos	1905147.827	2.911	-6032272.479	3.482	-810729.775	3.001
75	Mahe	3602828.788	3.024	-5238237.170	3.096	-515947.433	2.773
111	Wrightwood	-2448831.364	2.679	4667972.160	3.052	3582744.578	3.162

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Table 2.1-3 GEM 6 Station Coordinates

STATION POSITIONS FOR DOPPLER

STATION NAME	STATION NUMBER	LATITUDE DEG	LATITUDE MN	LATITUDE SECOND	LONGITUDE DEG	LONGITUDE MN	LONGITUDE SECOND	HEIGHT METERS	SIGMA
ANCHOR	2014	61	17	0.168	210	10	29.035	63.9	5.
TAFUNA	2017	-14	19	49.937	189	17	3.046	27.4	5.
THOLEG	2018	76	32	19.344	291	13	54.033	51.9	10.
MCMRDO	2019	-77	50	52.257	166	40	25.770	-33.1	11.
WAHIWA	2100	21	31	15.531	202	0	10.436	395.6	4.
LACRES	2103	32	16	44.522	253	14	45.428	1150.7	5.
LASHM2	2106	51	11	9.367	358	58	25.532	217.8	4.
APLMND	2111	39	9	48.588	283	6	11.907	96.0	4.
PRETOR	2115	-25	56	48.272	28	20	52.046	1582.6	6.
ASAMOA	2117	-14	19	50.265	189	17	2.891	39.5	5.
WALDOP	2203	37	51	52.094	284	29	32.286	-38.0	12.
ASCION	2722	- 7	58	9.757	345	35	40.701	88.6	10.
COCOSL	2723	-12	11	44.560	96	50	3.054	-44.3	16.
MOSLAK	2738	47	11	7.247	240	39	43.766	338.3	15.
STNVIL	2745	33	25	32.087	269	5	9.799	-2.5	46.
MESHED	2817	36	14	26.485	59	37	44.239	950.8	5.
FRTLMY	2822	12	7	53.927	15	2	6.787	298.5	7.
NATLDP	2837	- 5	54	57.998	324	49	55.950	3.9	6.

STATION POSITIONS FOR MOTS

STATION NAME	STATION NUMBER	LATITUDE DEG	LATITUDE MN	LATITUDE SECOND	LONGITUDE DEG	LONGITUDE MN	LONGITUDE SECOND	HEIGHT METERS	SIGMA
1BPOIN	1021	38	25	50.253	282	54	48.699	-38.2	3.
1FTMYR	1022	26	32	53.359	278	8	4.161	-35.9	3.
1OOMER	1024	-31	23	24.970	136	52	15.455	128.6	5.
1QUITO	1025	0	37	21.567	281	25	16.401	3571.8	19.
1SATAG	1028	-33	8	58.448	289	19	53.576	709.3	5.
1MOJAV	1030	35	19	47.931	243	5	59.055	886.2	3.
1JOBUR	1031	-25	53	0.843	27	42	26.404	1537.2	3.
1NEWFL	1032	47	44	29.838	307	16	46.121	64.2	8.
1GFORK	1034	48	1	21.344	262	59	19.513	216.4	3.
1WNKFL	1035	51	26	46.148	359	18	8.330	97.3	5.
1ULASK	1036	64	58	37.046	212	28	31.715	284.1	8.
1ROSMN	1037	35	12	7.388	277	7	41.321	864.1	3.
1ORORL	1038	-35	37	32.106	148	57	14.825	943.5	4.
1ROSMA	1042	35	12	7.408	277	7	41.021	864.1	3.
1TANAN	1043	-19	0	31.860	47	17	59.360	1362.2	6.
1UNDAK	7034	48	1	21.344	262	59	19.513	215.4	3.
1EDINB	7036	26	22	46.743	261	40	7.459	20.9	3.
1COLBA	7037	38	53	36.207	267	47	40.940	227.4	3.
1BERMD	7039	32	21	49.826	295	20	35.069	-14.9	4.
1PURIO	7040	18	15	28.817	294	0	23.584	-10.4	3.
1GFSCP	7043	39	1	15.716	283	10	20.528	10.1	3.
1DENVR	7045	39	38	48.056	255	23	38.640	1757.8	3.
1JUM24	7071	27	1	14.010	279	53	12.657	-26.9	3.
1JUM40	7072	27	1	14.388	279	53	12.844	-26.1	3.
1JUPC1	7073	27	1	14.372	279	53	13.060	-26.6	3.
1JUBC4	7074	27	1	14.570	279	53	13.107	-25.9	3.
1SUDBR	7075	46	27	21.306	279	3	10.514	235.5	3.
1JAMAC	7076	18	4	34.700	283	11	27.038	417.9	5.
1GFSCN	7077	38	59	57.438	283	9	37.906	7.1	3.
WALMOT	7078	37	51	47.543	284	29	27.717	-39.6	5.

Table 2.1-3 cont.

STATION POSITIONS FOR BAKER-NUNN

STATION NAME	STATION NUMBER	LATITUDE DEG	LATITUDE MN	LATITUDE SECOND	LONGITUDE DEG	LONGITUDE MN	LONGITUDE SECOND	HEIGHT METERS	SIGMA
1ORGAN	9001	32	25	25.079	253	26	48.996	1619.1	4.
1OLFAN	9002	-25	57	35.837	28	14	52.459	1559.0	3.
WOOMER	9003	-31	6	2.124	136	47	3.319	155.5	4.
1SPAIN	9004	36	27	46.818	353	47	36.958	60.0	3.
1TOKYO	9005	35	40	22.968	139	32	16.563	84.9	5.
1NATAL	9006	29	21	34.781	79	27	27.517	1871.0	4.
1QUIPA	9007	-16	27	56.628	288	30	24.604	2484.7	4.
1CURAC	9008	29	38	13.839	52	31	11.372	1580.3	6.
1SHRAZ	9009	12	5	25.186	291	9	44.532	-23.2	5.
1JUPTR	9010	27	1	14.120	279	53	13.357	-24.8	3.
1VILDO	9011	-31	56	34.597	294	53	36.609	625.1	4.
1MAUIO	9012	20	42	26.175	203	44	33.983	3042.8	4.
HOPKIN	9021	31	41	3.302	249	7	18.599	2341.0	7.
AUSBAK	9023	-31	23	25.697	136	52	43.649	134.0	4.
DODAIR	9025	36	0	20.304	139	11	31.565	883.7	5.
DEZEIT	9028	8	44	51.242	38	57	33.407	1904.1	5.
COMRIV	9031	-45	53	12.290	292	23	9.413	192.5	6.
JUPGEO	9049	27	1	13.948	279	53	12.993	-28.1	3.
AGASSI	9050	42	30	21.542	288	26	30.583	129.9	22.
GREECE	9091	38	4	44.849	23	55	58.658	487.2	5.
COLDLK	9424	54	44	34.634	249	57	23.125	669.4	15.
EDWAFB	9425	34	57	50.677	242	5	8.030	748.9	6.
OSLONR	9426	60	12	39.200	10	45	2.938	617.0	17.
JOHNST	9427	16	44	38.879	190	29	9.343	18.8	8.

STATION POSITIONS FOR GRARR

STATION NAME	STATION NUMBER	LATITUDE DEG	LATITUDE MN	LATITUDE SECOND	LONGITUDE DEG	LONGITUDE MN	LONGITUDE SECOND	HEIGHT METERS	SIGMA
MADGAR	1122	-19	1	16.314	47	18	15.185	1349.6	50.
MADGAS	1123	-19	1	14.392	47	18	11.335	1387.6	7.
ROSRAN	1126	35	11	45.528	277	7	26.240	828.1	3.
ULASKR	1128	64	58	18.964	212	29	12.728	338.8	3.
CARVON	1152	-24	54	11.015	113	42	59.302	2.5	4.

STATION POSITIONS FOR C-BAND

STATION NAME	STATION NUMBER	LATITUDE DEG	LATITUDE MN	LATITUDE SECOND	LONGITUDE DEG	LONGITUDE MN	LONGITUDE SECOND	HEIGHT METERS	SIGMA
ETRPRE	4050	-25	56	37.592	28	21	28.937	1588.6	12.
ETRMRT	4082	28	25	28.943	279	20	7.649	-30.7	5.
NBER34	4740	32	20	53.337	295	20	46.909	-26.9	4.
NWALI8	4840	37	50	29.160	284	30	53.007	-39.4	4.
NWALI3	4860	37	51	37.279	284	29	25.864	-36.4	4.
NBER05	4760	32	20	52.837	295	20	47.119	24.9	4.
WOOR38	4946	-30	49	5.877	136	50	17.532	124.3	6.

Table 2.1-3 cont.

STATION POSITIONS FOR BC-4

STATION NAME	STATION NUMBER	LATITUDE DEG	LATITUDE MN	LATITUDE SECOND	LONGITUDE DEG	LONGITUDE MN	LONGITUDE SECOND	HEIGHT METERS	SIGMA
BELTSV	6002	39	1	39.706	283	10	27.538	0.1	3.
MOSELK	6003	47	11	6.660	240	39	43.768	331.6	9.
SHEMYA	6004	52	42	48.985	174	07	26.363	38.3	22.
TROMSO	6006	69	39	44.108	18	56	29.299	109.3	15.
TRCERA	6007	38	45	36.426	332	54	25.707	99.9	11.
PARMBO	6008	5	26	53.866	304	47	40.707	-30.2	15.
QUITO	6009	- 0	5	51.408	281	34	47.674	2685.5	17.
MAUIO	6011	20	42	27.235	203	44	38.433	3057.8	4.
WAKEIS	6012	19	17	28.643	166	36	39.443	-15.6	12.
KANOYA	6013	31	23	42.733	130	52	16.579	76.1	17.
CATNIA	6016	37	26	38.374	15	2	45.352	38.6	9.
MASHAD	6015	36	14	25.459	59	37	43.740	947.7	9.
VILDOL	6019	-31	56	35.317	294	53	38.999	625.1	4.
EASTER	6020	-27	10	36.330	250	34	22.636	199.6	22.
TUTILA	6022	-14	19	54.394	189	17	8.692	15.5	11.
THRUSD	6023	-10	35	3.276	142	12	39.420	107.9	10.
INVERC	6031	-46	24	58.309	168	19	31.502	-11.5	9.
CAVERS	6032	-31	50	25.036	115	58	31.671	-18.1	7.
SOCORO	6038	18	43	58.568	249	2	41.347	-23.0	10.
PITCRN	6039	-25	4	6.765	229	53	12.572	295.2	25.
COCOSI	6040	-12	11	43.990	96	50	2.460	-47.8	11.
ADISBA	6042	8	46	12.504	38	59	52.089	1865.2	5.
CERROS	6043	-52	46	52.600	290	46	34.090	78.3	11.
HEARDI	6044	-53	1	9.425	73	23	34.212	34.8	16.
MAURIT	6045	-20	13	52.901	57	25	31.944	133.1	11.
ZAMBGA	6047	6	55	20.395	122	4	8.907	59.3	14.
PALMER	6050	-64	46	26.371	295	56	53.697	23.1	15.
MAWSON	6051	-67	36	4.268	62	52	22.242	28.8	11.
WILKES	6052	-66	16	44.937	110	32	7.169	-5.5	11.
MCMRDO	6053	-77	50	41.846	166	38	31.279	-56.0	10.
ASCENS	6055	- 7	58	15.213	345	35	34.770	70.1	9.
XMASIL	6059	2	0	18.617	202	35	16.306	2.3	11.
CULGDA	6060	-30	18	34.411	149	33	40.993	226.2	7.
SGAISL	6061	-54	17	0.709	323	30	21.877	2.0	12.
DAKAR	6063	14	44	42.292	342	31	0.697	44.3	9.
FORTLY	6064	12	7	54.697	15	2	7.246	296.4	7.
HOHNBG	6065	47	48	3.758	11	1	25.916	970.1	12.
NATALB	6067	- 5	55	38.935	324	50	4.707	13.2	10.
JOBURG	6068	-25	52	58.963	27	42	23.644	1539.2	3.
TRSUNA	6069	-37	3	53.227	347	41	5.670	25.3	19.
CHIMAI	6072	18	46	10.593	98	58	2.372	245.9	14.
DGOGRA	6073	- 7	21	6.513	72	28	20.592	-77.9	12.
MAHE	6075	- 4	40	14.620	55	28	47.950	534.4	12.
PRTVLA	6078	-17	41	31.834	168	18	24.472	54.4	37.
WRIGHT	6111	34	22	54.548	242	19	5.990	2247.7	6.
PRBARW	6123	71	18	48.393	203	21	8.504	-34.0	26.
WRIGHT	6134	34	22	44.455	242	19	5.765	2161.8	6.

STATION POSITIONS FOR LASER

STATION NAME	STATION NUMBER	LATITUDE DEG	LATITUDE MN	LATITUDE SECOND	LONGITUDE DEG	LONGITUDE MN	LONGITUDE SECOND	HEIGHT METERS	SIGMA
GODLAS	7050	39	1	14.387	283	10	18.638	11.1	3.
WALLAS	7052	37	51	36.199	284	29	23.965	-42.4	3.
CRMLAS	7054	-24	54	15.965	113	42	58.252	-3.5	4.

Table 2.1-4
SAO Cartesian Coordinates
(Standard Earth III)

7050	1.1306743	-4.8313729	3.9941017	1.78	GREENBELT ,USA
1021	1.1180312	-4.8163207	3.9429737	1.78	BLOSSOM POINT,USA
7060	-5.0689640	3.5841060	1.4587449	2.85	GUAM,USA
7816	4.6543370	1.9591789	3.8843585	2.26	STEPHANION,GREECE
7818	5.4263281	-.2293265	3.3346064	6.07	COLOMB-BECHAR,ALGERIA
8015	4.5783280	.4579749	4.4031809	1.93	HAUTE PROVENCE,FRANCE
7815	4.5783710	.4579592	4.4031367	1.93	HAUTE PROVENCE,FRANCE
7809	4.5783487	.4579660	4.4031591	1.93	HAUTE PROVENCE,FRANCE
9001	-1.5357682	-5.1669893	3.4010415	2.20	ORGAN PASS,USA
7901	-1.5357682	-5.1669893	3.4010415	2.20	ORGAN PASS,USA
9002	5.0561270	2.7165136	-2.7757817	1.76	OLIFANTSFONTEIN,REP.S.AFR.
7902	5.0561268	2.7165135	-2.7757817	1.76	OLIFANTSFONTEIN,REP.S.AFR.
9022	5.0561210	2.7165243	-2.7757864	1.76	OLIFANTSFONTEIN,REP.S.AFR.
9003	-3.9837782	3.7430941	-3.2765608	2.46	WOOMERA,AUSTRALIA
9023	-3.9777667	3.7251063	-3.3030281	2.14	ISLAND LAGOON,AUSTRALIA
9004	5.1055915	-.5552314	3.7696610	2.50	SAN FERNANDO,SPAIN
7804	5.1056116	-.5552537	3.7696297	2.50	SAN FERNANDO,SPAIN
9005	-3.9466015	3.3662968	3.6988329	5.68	TOKYO,JAPAN
9025	-3.9104351	3.3763585	3.7296197	5.68	DODAIRA,JAPAN
9006	1.0182046	5.4711062	3.1090230	2.65	NAINI TAL,INDIA
9007	1.9427753	-5.8040895	-1.7969302	1.91	AREQUIPA,PERU
7907	1.9427754	-5.8040899	-1.7969303	1.91	AREQUIPA,PERU
9027	1.9427702	-5.8040962	-1.7969085	1.91	AREQUIPA,PERU
9008	3.3768947	4.4939808	3.1362527	4.21	SHIRAZ,IRAN
9009	2.2518227	-5.8169142	1.3271554	3.21	CURACAO,ANTILLES
9010	.9762876	-5.6013930	2.8802356	2.50	JUPITER,USA
9011	2.2805910	-4.9145740	-3.3554219	2.77	VILLA DOLORES,ARGENTINA
9012	-5.4660614	-2.4042796	2.2421798	2.55	MAUI,USA
7912	-5.4660646	-2.4042795	2.2421740	2.55	MAUI,USA
9020	5.8862328	-1.8456177	1.6152706	5.63	DAKAR,SENEGAL
7820	5.8862403	-1.8456349	1.6152390	5.63	DAKAR,SENEGAL
9021	-1.9367732	-5.0777080	3.3319034	2.96	MT. HOPKINS,USA
7921	-1.9367721	-5.0777050	3.3319086	2.96	MT. HOPKINS,USA
9028	4.9037592	3.9652149	.9638703	4.20	ADDIS ABABA,ETHIOPIA
9029	5.1864633	-3.6538631	-.6543322	3.54	NATAL,BRAZIL
7929	5.1864635	-3.6538633	-.6543323	3.54	NATAL,BRAZIL
9039	5.1864734	-3.6538423	-.6543319	3.54	NATAL,BRAZIL
9031	1.6938062	-4.1123361	-4.5566551	4.80	COMODORO RIVADAVIA,ARGENTINA
9091	4.5951674	2.0394651	3.9126562	3.38	DIONYSOS,GREECE
7930	4.5952233	2.0394473	3.9126096	3.38	DIONYSOS,GREECE
9030	4.5952144	2.0394471	3.9126195	3.38	DIONYSOS,GREECE
8019	4.5794767	.5860177	4.3864113	4.08	NICE,FRANCE
9066	4.3313071	.5675232	4.6330095	3.09	ZIMMERWALD,SWITZERLAND
9074	3.1838846	1.4214749	5.3228907	7.78	RIGA,LATVIA
9077	3.9074367	1.6024412	4.7638844	28.51	USHGOROD,USSR
9080	3.9201685	-.1347328	5.0127143	5.17	MALVERN,U.K.
9113	-2.4500899	-4.6249160	3.6350304	2.91	ROSAMOND,USA
9114	-1.2648450	-3.4968905	5.1854529	6.67	COLD LAKE,CANADA
9115	3.1212802	.5926412	5.5127002	8.29	HARESTUA,NORWAY
9117	-6.0074069	-1.1118594	1.8257364	5.63	JOHNSTON IS.,USA
4711	-2.3514480	-4.6450713	3.6737616	3.11	CALIFORNIA JPL,USA
4712	-2.3504615	-4.6519706	3.6656203	3.16	CALIFORNIA JPL,USA
4714	-2.3536402	-4.6413339	3.6770499	3.07	CALIFORNIA JPL,USA
4741	-3.9787020	3.7248591	-3.3022079	2.72	AUSTRALIA JPL
4742	-4.4609671	2.6824292	-3.6746136	5.99	AUSTRALIA JPL
4751	5.0854679	2.6682502	-2.7687255	4.72	SO. AFRICA JPL
4761	4.8492416	-.3602578	4.1146658	3.33	SPAIN JPL
4762	4.8466991	-.3702156	4.1166990	3.36	SPAIN JPL
6001	.5465802	-1.3899724	6.1802331	8.56	THULE,GREENLAND
6002	1.1387694	-4.8388351	3.9947009	2.33	BELTSVILLE,USA

Table 2.1-4 cont.

6003	-2.1279252	-3.7058479	4.6560291	5.81	MOSES LAKE,USA
6004	-3.8517719	.3964305	5.0513351	14.81	SHEMYA,USA
6006	2.1029462	.7216797	5.9581766	10.50	TROMSO,NORWAY
6007	4.4336636	-2.2681386	3.9716419	9.86	AZORES,PORTUGAL
6008	3.6232538	-5.2142307	.6015210	9.87	PARAMARIBO,NETHERLAND
6009	1.2808450	-6.2509432	-.0108257	11.52	QUITO,ECUADOR
6011	-5.4660121	-2.4043987	2.2422157	2.96	MAUI,USA
6012	-5.6585271	1.3945293	2.0937898	10.65	WAKE IS.,USA
6013	-3.5658487	4.1207293	3.3034203	6.87	KANOYA,JAPAN
6015	2.6043759	4.4441657	3.7503170	8.08	MASHHAD,IRAN
6016	4.8964108	1.3161796	3.8566669	9.45	CATANIA,ITALY
6019	2.2806423	-4.9145371	-3.3554408	3.15	VILLA DOLORES,ARGENTINA
6020	-1.8886003	-5.3548656	-2.8957715	15.03	EASTER IS.,CHILE
6022	-6.0999443	-.9973219	-1.5685988	9.67	TUTUILA,AM.SAMOA
6023	-4.9553522	3.8422666	-1.1638601	7.00	THURSDAY IS.,AUSTRALIA
6031	-4.3138002	.8913641	-4.5974824	7.22	INVERCARGILL,NEW ZEALAND
6032	-2.3753712	4.8755675	-3.3454051	9.21	CAVERSHAM,AUSTRALIA
6038	-2.1609763	-5.6426960	2.0353533	6.65	REVILLA GIGEDO,MEXICO
6039	-3.7247525	-4.4211996	-2.6661053	16.77	PITCAIRN IS.,U.K.
6040	-.7419387	6.1908089	-1.3385569	10.16	COCOS IS.,AUSTRALIA
6042	4.9007669	3.9682471	.9663325	4.28	ADDIS ABABA,ETHIOPIA
6043	1.3713928	-3.6147360	-5.0559687	9.76	CERRO SOMBRERO,CHILE
6044	1.0989263	3.6846476	-5.0718820	17.76	HEARD IS.,AUSTRALIA
6045	3.2234563	5.0453439	-2.1918098	7.18	MAURITIUS,U.K.
6047	-3.3619233	5.3658255	.7636213	9.96	ZAMBOANGA,PHILIPPINES
6050	1.1926968	-2.4509857	-5.7470749	15.05	PALMER STA.,ANTARCTIC
6051	1.1113623	2.1692819	-5.8743525	10.63	MAWSON STA.,ANTARCTIC
6052	-.9025769	2.4095502	-5.8165694	10.54	WILKES STA.,ANTARCTIC
6053	-1.3108204	.3112859	-6.2136991	10.28	MCMURDO STA.,ANTARCTIC
6055	6.1163500	-1.5717368	-.8786157	8.58	ASCENSION IS.,U.K.
6059	-5.8853247	-2.4483386	.2216579	8.16	CHRISTMAS IS.,U.K.
6060	-4.7516205	2.7920850	-3.2001809	3.12	CULGOORA,AUSTRALIA
6061	2.9999404	-2.2193504	-5.1552792	11.68	SO. GEORGIA,U.K.
6063	5.8844831	-1.6534871	1.6128451	8.59	DAKAR,SENEGAL
6064	6.0234086	1.6179375	1.3317269	7.65	FORT LAMY,CHAD
6065	4.2135828	.8208369	4.7027684	9.98	HOHENPEISSENBERG,W.GERMANY
6067	5.1864189	-3.6539247	-.6547953	3.81	NATAL,BRAZIL
6068	5.0848492	2.6703463	-2.7681134	2.34	JOHANNESBURG,REP.S.AFR.
6069	4.9784438	-1.0668586	-3.8231810	20.11	TRISTAN DA CUNHA,U.K.
6072	-.9416665	5.9674686	2.0393068	10.56	CHIANG MAI,THAILAND
6073	1.9651619	6.0322863	-.8107347	9.23	CHAGOS,ARCHIPELG
6075	3.6028434	5.2382434	-.5159484	8.77	SEYCHELLES,U.K.
6078	-5.9523028	1.2319403	-1.9259415	17.72	NEW HEBRIDES,U.K.
6111	-2.4488502	-4.6079695	3.5827477	3.07	WRIGHTWOOD,USA
6123	-1.8817832	-.8124222	6.0195890	13.49	POINT BARROW,USA
6134	-2.4489640	-4.6680599	3.5624423	3.14	WRIGHTWOOD,USA

2.14 ISAGEX Data

Laser and optical data from ISAGEX has been received (Attachment 2-1). The data is not validated.

Updated catalogue of simultaneous observations is expected in the near future.

2.15 Observational Ties Between BC-4 and Baker-Nunn Networks

In order to close some gaps in the OSU-WN net, new reduction of plates containing simultaneous events between BC-4 and Baker-Nunn Stations were requested. For related information and the listing of events involved see Enclosure 12 of the Eleventh Semiannual Status Report.

The data corresponding to the Baker-Nunn observations was received from SAO on September 23, 1973.

In order to reduce the BC-4 plates at New Mexico State University as specified in the above mentioned Report, the UT1 station times of each event at the BC-4 stations were needed.

On October 25, SAO provided the values A.S.-UT1 and the travel times between the satellite and the observing stations.

After processing the above SAO data the UT1 station times at the BC-4 stations were computed and sent to New Mexico State on November 13 (Table 2.1-5). The table is self explanatory. Punch-cards containing the date and the information on the right hand side of the second vertical dashed line were also supplied.

2.16 Other Material

Data from the WEST and the Euroafrique Satellite Geodesy projects were also requested and expected to arrive in the near future.

Table 2.1-5
Travel times: Baker Nunn-Satellite-BC4
and
UT1 times at the BC-4 Stations

DATE YR	MO	DY	MJD	SAO NO	(AS) HR MI SEC	AS-UT1	(UT1) HR MI SEC	R/C SAO-SAT	R/C BC4-SAT	R/C BC4-SAT	BC4 NO	(UT1) HR MI SEC	BC4 NO	(UT1) HR MI SEC
67	3	1	39550	9001	5 48 21.6463	5.42406	5 48 16.2222	0.0134	0.0155		6038	5 48 16.2243		
67	3	1	39550	9001	5 48 37.6465	5.42406	5 48 32.2224	0.0134	0.0154		6038	5 48 32.2244		
67	3	1	39550	9001	5 48 53.6469	5.42406	5 48 48.2228	0.0134	0.0153		6038	5 48 48.2247		
67	3	7	39556	9001	3 24 58.2428	5.43974	3 24 52.8031	0.0157	0.0186		6038	3 24 52.8060		
67	3	7	39556	9001	3 25 6.2431	5.43974	3 25 0.8034	0.0157	0.0185		6038	3 25 0.8062		
67	3	7	39556	9001	3 25 14.2431	5.43974	3 25 8.8034	0.0157	0.0185		6038	3 25 8.8062		
67	3	7	39556	9001	3 25 22.2434	5.43974	3 25 16.8037	0.0157	0.0185		6038	3 25 16.8065		
67	3	7	39556	9001	3 25 30.2436	5.43974	3 25 24.8039	0.0157	0.0185		6038	3 25 24.8067		
67	3	7	39556	9001	6 24 53.7407	5.44008	6 24 48.3006	0.0161	0.0174		6038	6 24 48.3019		
67	3	7	39556	9001	6 25 1.7406	5.44008	6 24 56.3005	0.0161	0.0174		6038	6 24 56.3018		
67	3	7	39556	9001	6 25 9.7407	5.44008	6 25 4.3006	0.0161	0.0174		6038	6 25 4.3019		
67	3	7	39556	9001	6 25 17.7407	5.44008	6 25 12.3006	0.0162	0.0173		6038	6 25 12.3017		
67	3	7	39556	9001	6 25 25.7407	5.44008	6 25 20.3006	0.0162	0.0173		6038	6 25 20.3017		
67	3	8	39557	9001	3 40 5.6458	5.44245	3 40 0.2034	0.0182	0.0178		6038	3 40 0.2030		
67	3	8	39557	9001	3 40 13.6457	5.44245	3 40 8.2033	0.0182	0.0178		6038	3 40 8.2029		
67	3	8	39557	9001	3 40 21.6457	5.44245	3 40 16.2033	0.0183	0.0178		6038	3 40 16.2028		
67	3	8	39557	9001	3 40 29.6457	5.44245	3 40 24.2032	0.0184	0.0178		6038	3 40 24.2026		
67	3	8	39557	9001	3 40 37.6458	5.44245	3 40 32.2033	0.0184	0.0179		6038	3 40 32.2028		
67	3	8	39557	9001	3 40 45.6461	5.44245	3 40 40.2036	0.0185	0.0179		6038	3 40 40.2030		
67	3	8	39557	9001	3 40 53.6458	5.44245	3 40 48.2033	0.0186	0.0179		6038	3 40 48.2026		
67	3	8	39557	9001	3 41 1.6457	5.44245	3 40 56.2032	0.0186	0.0180		6038	3 40 56.2026		
67	3	9	39558	9001	3 42 53.7709	5.44513	3 42 48.3258	0.0163	0.0168		6038	3 42 48.3263		
67	3	9	39558	9001	3 43 1.7702	5.44514	3 42 56.3251	0.0164	0.0168		6038	3 42 56.3255		
67	3	9	39558	9001	3 43 9.7707	5.44514	3 43 4.3256	0.0164	0.0168		6038	3 43 4.3260		
67	3	9	39558	9001	3 43 17.7708	5.44514	3 43 12.3257	0.0165	0.0168		6038	3 43 12.3260		
67	3	9	39558	9001	6 43 57.7521	5.44547	6 43 52.3066	0.0196	0.0182		6038	6 43 52.3052		
67	3	9	39558	9001	6 44 13.7512	5.44547	6 44 8.3057	0.0197	0.0182		6038	6 44 8.3042		
67	3	9	39558	9001	6 44 21.7508	5.44547	6 44 16.3053	0.0197	0.0182		6038	6 44 16.3038		
67	3	9	39559	9001	6 44 29.7503	5.44547	6 44 24.3048	0.0198	0.0182		6038	6 44 24.3032		
67	3	9	39558	9001	6 44 37.7500	5.44547	6 44 32.3045	0.0199	0.0183		6038	6 44 32.3029		
67	3	9	39558	9001	6 44 45.7498	5.44547	6 44 40.3043	0.0199	0.0183		6038	6 44 40.3027		
67	3	9	39558	9001	6 44 53.7495	5.44547	6 44 48.3040	0.0200	0.0183		6038	6 44 48.3023		
67	3	9	39558	9001	6 45 1.7493	5.44547	6 44 56.3038	0.0201	0.0183		6038	6 44 56.3020		
67	3	11	39560	9010	3 56 53.8790	5.45051	3 56 48.4285	0.0168	0.0160		6038	3 56 48.4277		
67	3	11	39560	9001	3 57 1.5359	5.45051	3 56 56.0854	0.0168	0.0160		6038	3 56 56.0846		
67	3	11	39560	9001	3 57 9.5359	5.45051	3 57 4.0854	0.0168	0.0161		6038	3 57 4.0847		
67	3	11	39560	9010	3 57 9.8787	5.45051	3 57 4.4282	0.0169	0.0161		6038	3 57 4.4274		
67	3	11	39560	9001	3 57 17.5358	5.45051	3 57 12.0853	0.0169	0.0161		6038	3 57 12.0845		
67	3	11	39560	9001	3 57 25.5356	5.45051	3 57 20.0851	0.0170	0.0161		6038	3 57 20.0842		
67	3	11	39560	9010	3 57 25.8790	5.45051	3 57 20.4285	0.0170	0.0161		6038	3 57 20.4276		
67	3	11	39560	9001	3 57 33.5358	5.45051	3 57 28.0853	0.0170	0.0161		6038	3 57 28.0844		
67	3	11	39560	9001	3 57 41.5356	5.45051	3 57 36.0851	0.0171	0.0161		6038	3 57 36.0841		
67	3	11	39560	9010	3 57 41.8792	5.45051	3 57 36.4287	0.0171	0.0161		6038	3 57 36.4277		
67	3	11	39560	9010	3 57 57.8795	5.45051	3 57 52.4290	0.0172	0.0162		6038	3 57 52.4280		
67	3	12	39561	9010	3 57 57.2434	5.45319	3 57 51.7902	0.0159	0.0155		6038	3 57 51.7898		
67	3	12	39561	9010	3 58 13.2438	5.45319	3 58 7.7906	0.0159	0.0155		6038	3 58 7.7902		
67	3	12	39561	9010	3 58 29.2438	5.45319	3 58 23.7906	0.0160	0.0155		6038	3 58 23.7901		
67	3	12	39561	9010	3 58 45.2440	5.45319	3 58 39.7908	0.0160	0.0154		6038	3 58 39.7902		
67	3	12	39561	9010	3 59 1.2446	5.45319	3 58 55.7914	0.0161	0.0154		6038	3 58 55.7907		
67	3	15	39564	9010	4 4 53.7551	5.46126	4 4 48.2938	0.0185	0.0189		6038	4 4 48.2942		
67	3	15	39564	9010	4 5 9.7534	5.46126	4 5 4.2921	0.0184	0.0188		6038	4 5 4.2925		
67	3	15	39564	9010	4 5 25.7526	5.46126	4 5 20.2913	0.0183	0.0186		6038	4 5 20.2916		
67	3	15	39564	9010	4 5 41.7520	5.46126	4 5 36.2907	0.0183	0.0184		6038	4 5 36.2908		
67	3	15	39564	9010	4 5 57.7514	5.46126	4 5 52.2901	0.0182	0.0183		6038	4 5 52.2902		
67	3	16	39565	9001	4 24 5.7107	5.46400	4 24 0.2467	0.0153	0.0146		6038	4 24 0.2460		
67	3	16	39565	9010	4 24 5.8360	5.46400	4 24 0.3720	0.0192	0.0146		6038	4 24 0.3674		
67	3	16	39565	9001	4 24 13.7106	5.46400	4 24 8.2466	0.0154	0.0146		6038	4 24 8.2458		
67	3	16	39565	9001	4 24 21.7103	5.46400	4 24 16.2463	0.0155	0.0146		6038	4 24 16.2454		

YR	MO	DY	MJD	SAO NO	(AS) HR MI SEC	AS-UT1	(UT1) HR MI SEC	R/C SAO-SAT	R/C BC4-SAT	R/C BC4-SAT	BC4 NO	(UT1) HR MI SEC	BC4 NO	(UT1) HR MI SEC
67	3	16	39565	9010	4 24 21.8342	5.46400	4 24 16.3702	0.0193	0.0146		6038	4 24 16.3655		
67	3	16	39565	9001	4 24 29.7102	5.46400	4 24 24.2462	0.0155	0.0146		6038	4 24 24.2453		
67	3	16	39565	9001	4 24 37.7100	5.46400	4 24 32.2460	0.0156	0.0146		6038	4 24 32.2450		
67	3	16	39565	9010	4 24 37.8327	5.46400	4 24 32.3687	0.0194	0.0146		6038	4 24 32.3639		
67	3	16	39565	9010	4 24 53.8314	5.46400	4 24 48.3674	0.0195	0.0146		6038	4 24 48.3625		
67	3	17	39566	9010	4 23 49.7202	5.46669	4 23 44.2535	0.0187	0.0154		6038	4 23 44.2502		
67	3	17	39566	9010	4 24 5.7247	5.46670	4 24 0.2580	0.0187	0.0153		6038	4 24 0.2546		
67	3	17	39566	9010	4 24 21.7295	5.46670	4 24 16.2628	0.0188	0.0152		6038	4 24 16.2592		
67	3	17	39566	9010	4 24 37.7348	5.46670	4 24 32.2681	0.0189	0.0152		6038	4 24 32.2645		
67	3	17	39566	9010	4 24 53.6787	5.46670	4 24 48.2120	0.0188	0.0151		6038	4 24 48.2083		
67	3	21	39570	9001	4 41 10.0537	5.47752	4 41 4.5762	0.0153	0.0185		6038	4 41 4.5794		
67	3	21	39570	9001	4 41 18.0537	5.47752	4 41 12.5762	0.0152	0.0184		6038	4 41 12.5794		
67	3	21	39570	9001	4 41 26.0538	5.47752	4 41 20.5763	0.0152	0.0184		6038	4 41 20.5795		
67	3	21	39570	9001	4 41 34.0541	5.47752	4 41 28.5766	0.0152	0.0183		6038	4 41 28.5797		
67	3	21	39570	9001	4 41 42.0543	5.47752	4 41 36.5768	0.0152	0.0182		6038	4 41 36.5798		
67	3	26	39575	9001	5 13 58.3214	5.49109	5 13 52.8303	0.0174	0.0189		6038	5 13 52.8318		
67	3	26	39575	9001	5 14 6.3212	5.49109	5 14 0.8301	0.0174	0.0188		6038	5 14 0.8315		
67	3	26	39575	9001	5 14 14.3211	5.49110	5 14 8.8300	0.0174	0.0188		6038	5 14 8.8314		
67	3	26	39575	9001	5 14 22.3209	5.49110	5 14 16.8298	0.0174	0.0188		6038	5 14 16.8312		
67	3	26	39575	9001	5 14 30.3208	5.49110	5 14 24.8297	0.0175	0.0188		6038	5 14 24.8310		
67	3	26	39575	9001	5 14 38.3208	5.49110	5 14 32.8297	0.0175	0.0187		6038	5 14 32.8309		
67	3	26	39575	9001	5 14 46.3206	5.49110	5 14 40.8295	0.0175	0.0187		6038	5 14 40.8307		
67	3	26	39575	9001	5 14 54.3207	5.49110	5 14 48.8296	0.0175	0.0187		6038	5 14 48.8308		
67	3	26	39575	9001	5 15 2.3206	5.49110	5 14 56.8295	0.0175	0.0186		6038	5 14 56.8306		
67	3	29	39578	9001	5 36 21.8718	5.49930	5 36 16.3725	0.0206	0.0203		6038	5 36 16.3722		
67	3	29	39578	9001	5 36 37.8717	5.49930	5 36 32.3724	0.0207	0.0203		6038	5 36 32.3720		
67	3	29	39578	9001	5 36 53.8717	5.49930	5 36 48.3724	0.0208	0.0203		6038	5 36 48.3719		
67	3	29	39578	9001	5 37 9.8716	5.49930	5 37 4.3723	0.0209	0.0204		6038	5 37 4.3718		
67	3	29	39578	9001	5 37 25.8725	5.49930	5 37 20.3732	0.0210	0.0204		6038	5 37 20.3726		
67	3	29	39578	9001	5 37 41.8732	5.49930	5 37 36.3739	0.0211	0.0204		6038	5 37 36.3732		
67	3	29	39578	9001	5 37 57.8741	5.49931	5 37 52.3748	0.0212	0.0204		6038	5 37 52.3740		
67	3	31	39580	9001	5 47 33.5327	5.50483	5 47 28.0279	0.0220	0.0219		6038	5 47 28.0278		
67	3	31	39580	9001	5 47 49.6483	5.50483	5 47 44.1435	0.0221	0.0219		6038	5 47 44.1433		
67	3	31	39580	9001	5 48 5.6477	5.50483	5 48 0.1429	0.0222	0.0219		6038	5 48 0.1426		
67	3	31	39580	9001	5 48 21.6477	5.50483	5 48 16.1429	0.0223	0.0219		6038	5 48 16.1425		
67	3	31	39580	9001	5 48 37.6473	5.50483	5 48 32.1425	0.0224	0.0219		6038	5 48 32.1420		
67	3	31	39580	9001	5 48 53.6475	5.50483	5 48 48.1427	0.0225	0.0220		6038	5 48 48.1422		
67	4	2	39582	9001	2 53 42.0404	5.51001	2 53 36.5304	0.0142	0.0168		6038	2 53 36.5330		
67	4	2	39582	9001	2 53 50.0402	5.51001	2 53 44.5302	0.0142	0.0168		6038	2 53 44.5328		
67	4	2	39582	9001	2 53 58.0403	5.51001	2 53 52.5303	0.0142	0.0167		6038	2 53 52.5328		
67	4	2	39582	9001	2 54 6.0403	5.51001	2 54 0.5303	0.0142	0.0167		6038	2 54 0.5328		
67	4	3	39583	9010	2 56 37.6279	5.51278	2 56 32.1151	0.0190	0.0179		6038	2 56 32.1140		
67	4	3	39583	9010	2 56 53.6284	5.51278	2 56 48.1156	0.0190	0.0178		6038	2 56 48.1144		
67	4	3	39583	9010	2 57 9.6291	5.51278	2 57 4.1163	0.0190	0.0177		6038	2 57 4.1150		
67	4	3	39583	9010	2 57 25.6301	5.51278	2 57 20.1173	0.0189	0.0176		6038	2 57 20.1160		
67	4	3	39583	9010	2 57 41.6312	5.51278	2 57 36.1184	0.0189	0.0175		6038	2 57 36.1170		
67	4	3	39583	9010	2 57 57.6324	5.51278	2 57 52.1196	0.0189	0.0173		6038	2 57 52.1180		
67	4	7	39587	9010	3 24 22.2507	5.52388	3 24 16.7268	0.0218	0.0167		6038	3 24 16.7217		
67	4	7	39587	9010	3 24 38.2507	5.52388	3 24 32.7268	0.0218	0.0166		6038	3 24 32.7216		
67	4	7	39587	9010	3 24 54.2509	5.52388	3 24 48.7270	0.0218	0.0166		6038	3 24 48.7218		
67	4	7	39587	9010	3 25 10.2516	5.52388	3 25 4.7277	0.0219	0.0165		6038	3 25 4.7223		
67	4	7	39587	9010	3 25 26.2520	5.52389	3 25 20.7281	0.0219	0.0165		6038	3 25 20.7227		
67	4	8	39588	9001	3 24 5.6005	5.52664	3 24 0.0739	0.0160	0.0191		6038	3 24 0.0770		
67	4	8	39588	9001	3 24 13.6005	5.52664	3 24 8.0739	0.0160	0.0191		6038	3 24 8.0770		
67	4	8	39588	9001	3 24 29.6004	5.52664	3 24 24.0738	0.0159	0.0190		6038	3 24 24.0769		
67	4	8	39588	9010	3 24 37.5987	5.52664	3 24 32.0721	0.0222	0.0189		6038	3 24 32.0688		
67	4	8	39588	9001	3 24 37.6004	5.52664	3 24 32.0738	0.0159	0.0189		6038	3 24 32.0768		
67	4	8	39588	9001	3 24 45.6004	5.52664	3 24 40.0738	0.0159	0.0188		6038	3 24 40.0767		
67	4	8	39588	9010	3 24 53.5989	5.52664	3 24 48.0723	0.0222	0.0188		6038	3 24 48.0689		

Table 2.1-5 cont.

YR	MO	DY	MJD	SAO NO	(AS) HR MI SEC	AS-UT1	(UT1) HR MI SEC	R/C SAO-SAT	R/C BC4-SAT	R/C BC4-SAT	BC4 NO	(UT1) HR MI SEC	BC4 NO	(UT1) HR MI SEC
67	4	8	39588	9001	3 24 53.6005	5.52664	3 24 48.0739	0.0159	0.0188		6038	3 24 48.0768		
67	4	8	39588	9001	3 25 1.6006	5.52664	3 24 56.0740	0.0159	0.0187		6038	3 24 56.0768		
67	4	8	39588	9010	3 25 9.5995	5.52664	3 25 4.0729	0.0222	0.0187		6038	3 25 4.0694		
67	4	8	39588	9010	3 25 25.6001	5.52664	3 25 20.0735	0.0222	0.0185		6038	3 25 20.0698		
67	4	8	39588	9010	3 25 41.6008	5.52664	3 25 36.0742	0.0222	0.0184		6038	3 25 36.0704		
67	5	26	39636	9001	10 16 6.5199	5.65849	10 16 0.8614	0.0126	0.0163		6038	10 16 0.8651		
67	5	26	39636	9001	10 16 22.5201	5.65849	10 16 16.8616	0.0127	0.0164		6038	10 16 16.8653		
67	5	26	39636	9001	10 16 38.5207	5.65849	10 16 32.8622	0.0128	0.0166		6038	10 16 32.8660		
67	5	26	39636	9001	10 16 54.5220	5.65849	10 16 48.8635	0.0129	0.0168		6038	10 16 48.8674		
67	5	26	39636	9001	10 17 10.5226	5.65849	10 17 4.8641	0.0130	0.0170		6038	10 17 4.8681		
67	6	10	39651	9010	8 34 5.7623	5.69158	8 34 0.0707	0.0111	0.0162		6038	8 34 0.0758		
67	6	10	39651	9010	8 34 13.7630	5.69158	8 34 8.0714	0.0111	0.0162		6038	8 34 8.0765		
67	6	10	39651	9010	8 34 21.7634	5.69158	8 34 16.0718	0.0111	0.0162		6038	8 34 16.0769		
67	6	10	39651	9010	8 34 29.7641	5.69158	8 34 24.0725	0.0111	0.0162		6038	8 34 24.0776		
67	6	10	39651	9010	8 34 45.7648	5.69158	8 34 40.0732	0.0111	0.0163		6038	8 34 40.0784		
67	6	10	39651	9010	8 34 53.7652	5.69158	8 34 48.0736	0.0111	0.0163		6038	8 34 48.0788		
67	6	10	39651	9010	8 35 1.7655	5.69158	8 34 56.0739	0.0111	0.0163		6038	8 34 56.0791		
67	6	11	39652	9001	8 39 57.9648	5.69366	8 39 52.2711	0.0143	0.0155		6038	8 39 52.2723		
67	6	11	39652	9001	8 40 5.9645	5.69366	8 40 0.2708	0.0142	0.0155		6038	8 40 0.2721		
67	6	11	39652	9001	8 40 13.9644	5.69366	8 40 8.2707	0.0142	0.0155		6038	8 40 8.2720		
67	6	11	39652	9001	8 40 21.9642	5.69366	8 40 16.2705	0.0142	0.0156		6038	8 40 16.2719		
67	6	11	39652	9001	8 40 29.9639	5.69366	8 40 24.2702	0.0141	0.0156		6038	8 40 24.2717		
67	6	11	39652	9001	8 40 37.9639	5.69366	8 40 32.2702	0.0141	0.0156		6038	8 40 32.2717		
67	6	11	39652	9001	8 40 45.9639	5.69366	8 40 40.2702	0.0141	0.0157		6038	8 40 40.2718		
67	6	15	39656	9001	8 55 57.8967	5.70167	8 55 52.1950	0.0162	0.0136		6038	8 55 52.1924		
67	6	15	39656	9001	8 56 13.8960	5.70167	8 56 8.1943	0.0160	0.0135		6038	8 56 8.1918		
67	6	15	39656	9001	8 56 29.8952	5.70168	8 56 24.1935	0.0158	0.0135		6038	8 56 24.1912		
67	6	15	39656	9001	8 56 45.8946	5.70168	8 56 40.1929	0.0156	0.0134		6038	8 56 40.1907		
67	6	15	39656	9001	8 57 1.8940	5.70168	8 56 56.1923	0.0155	0.0133		6038	8 56 56.1901		
67	6	27	39668	9001	10 8 29.8081	5.72438	10 8 24.0837	0.0164	0.0135		6038	10 8 24.0808		
67	6	27	39668	9001	10 8 45.8074	5.72438	10 8 40.0830	0.0163	0.0135		6038	10 8 40.0802		
67	6	27	39668	9001	10 9 1.8070	5.72438	10 8 56.0826	0.0162	0.0135		6038	10 8 56.0799		
67	6	27	39668	9001	10 9 17.8065	5.72438	10 9 12.0821	0.0161	0.0135		6038	10 9 12.0795		
67	6	27	39668	9001	10 9 33.8055	5.72438	10 9 28.0811	0.0160	0.0135		6038	10 9 28.0786		
67	6	27	39668	9001	10 9 49.8044	5.72438	10 9 44.0800	0.0159	0.0135		6038	10 9 44.0776		
67	6	27	39668	9001	10 10 5.8032	5.72438	10 10 0.0788	0.0158	0.0135		6038	10 10 0.0765		
67	6	28	39669	9001	7 17 57.9359	5.72594	7 17 52.2100	0.0156	0.0169		6038	7 17 52.2113		
67	6	28	39669	9001	7 18 13.9363	5.72594	7 18 8.2104	0.0156	0.0169		6038	7 18 8.2117		
67	6	28	39669	9001	7 18 29.9372	5.72594	7 18 24.2113	0.0155	0.0170		6038	7 18 24.2128		
67	6	28	39669	9001	7 18 45.9381	5.72594	7 18 40.2122	0.0155	0.0170		6038	7 18 40.2137		
67	6	28	39669	9001	7 19 1.9395	5.72594	7 18 56.2136	0.0154	0.0171		6038	7 18 56.2153		
67	6	28	39669	9001	10 15 18.2368	5.72616	10 15 12.5106	0.0166	0.0141		6038	10 15 12.5081		
67	6	28	39669	9001	10 15 34.2351	5.72616	10 15 28.5089	0.0165	0.0141		6038	10 15 28.5065		
67	6	28	39669	9001	10 15 50.2333	5.72616	10 15 44.5071	0.0164	0.0142		6038	10 15 44.5049		
67	6	28	39669	9001	10 16 6.2314	5.72616	10 16 0.5052	0.0163	0.0142		6038	10 16 0.5031		
67	6	28	39669	9001	10 16 22.2293	5.72616	10 16 16.5031	0.0162	0.0142		6038	10 16 16.5011		
67	6	28	39669	9001	10 16 38.2271	5.72616	10 16 32.5009	0.0161	0.0142		6038	10 16 32.4990		
67	6	28	39669	9001	10 17 10.2218	5.72616	10 17 4.4956	0.0160	0.0143		6038	10 17 4.4939		
67	6	30	39671	9001	10 27 34.4775	5.72969	10 27 28.7478	0.0177	0.0156		6038	10 27 28.7457		
67	6	30	39671	9001	10 27 50.4763	5.72969	10 27 44.7466	0.0176	0.0156		6038	10 27 44.7446		
67	6	30	39671	9001	10 28 6.4750	5.72969	10 28 0.7453	0.0175	0.0157		6038	10 28 0.7435		
67	6	30	39671	9001	10 28 22.4734	5.72969	10 28 16.7437	0.0174	0.0157		6038	10 28 16.7420		
67	6	30	39671	9001	10 28 38.4718	5.72969	10 28 32.7421	0.0174	0.0157		6038	10 28 32.7404		
67	7	13	39684	9010	8 42 13.8938	5.75119	8 42 8.1426	0.0217	0.0147		6038	8 42 8.1356		
67	7	13	39684	9010	8 42 29.8960	5.75119	8 42 24.1448	0.0217	0.0148		6038	8 42 24.1379		
67	7	13	39684	9010	8 42 45.8965	5.75119	8 42 40.1453	0.0217	0.0149		6038	8 42 40.1385		
67	7	13	39684	9010	8 43 1.8976	5.75119	8 42 56.1464	0.0217	0.0150		6038	8 42 56.1397		
67	7	25	39696	9010	6 35 49.5687	5.77007	6 35 43.7986	0.0175	0.0143		6038	6 35 43.7954		
67	7	25	39696	9010	6 36 5.5677	5.77007	6 35 59.7976	0.0174	0.0144		6038	6 35 59.7946		

Table 2.1-5 cont.

DATE YR	MO	DY	MJD	SAO NO	(AS) HR MI SEC	AS-UT1	(UT1) HR MI SEC	R/C SAO-SAT	R/C BC4-SAT	R/C BC4-SAT	BC4 NO	(UT1) HR MI SEC	BC4 NO	(UT1) HR MI SEC
67	7	25	39696	9010	6 36 21.5682	5.77007	6 36 15.7981	0.0174	0.0144		6038	6 36 15.7951		
67	7	25	39696	9010	6 36 37.5678	5.77007	6 36 31.7977	0.0174	0.0145		6038	6 36 31.7948		
67	7	25	39696	9010	6 36 53.5672	5.77007	6 36 47.7971	0.0174	0.0146		6039	6 36 47.7943		
67	8	7	39709	9001	7 33 9.5411	5.79175	7 33 3.7493	0.0192	0.0207		6038	7 33 3.7508		
67	8	7	39709	9001	7 33 25.5411	5.79175	7 33 19.7493	0.0193	0.0208		6038	7 33 19.7508		
67	8	7	39709	9001	7 33 41.5411	5.79175	7 33 35.7493	0.0194	0.0209		6038	7 33 25.7508		
67	8	7	39709	9001	7 33 57.5409	5.79176	7 33 51.7491	0.0194	0.0211		6038	7 33 51.7508		
67	8	7	39709	9001	7 34 13.5407	5.79176	7 34 7.7489	0.0195	0.0212		6038	7 34 7.7506		
67	9	11	39744	9023	10 52 3.5002	5.85833	10 51 57.6419	0.0156	0.0160	0.0169	6032	10 51 57.6423	6060	10 51 57.6432
67	9	11	39744	9023	10 52 19.5007	5.85833	10 52 13.6424	0.0154	0.0158	0.0168	6032	10 52 13.6428	6060	10 52 13.6438
67	9	11	39744	9023	10 52 35.5010	5.85833	10 52 29.6427	0.0153	0.0157	0.0166	6032	10 52 29.6431	6060	10 52 29.6440
67	9	11	39744	9023	10 52 51.5017	5.85833	10 52 45.6429	0.0151	0.0156	0.0165	6032	10 52 45.6434	6060	10 52 45.6443
67	9	11	39744	9023	10 53 7.5018	5.85834	10 53 1.6435	0.0149	0.0154	0.0163	6032	10 53 1.6440	6060	10 53 1.6449
67	9	11	39744	9023	10 53 23.5019	5.85834	10 53 17.6436	0.0148	0.0153	0.0162	6032	10 53 17.6441	6060	10 53 17.6450
67	9	11	39744	9023	10 53 39.5022	5.85834	10 53 33.6439	0.0147	0.0152	0.0161	6032	10 53 33.6444	6060	10 53 33.6453
67	9	11	39744	9023	10 53 55.5021	5.85834	10 53 49.6438	0.0145	0.0151	0.0159	6032	10 53 49.6444	6060	10 53 49.6452
67	9	16	39749	9023	11 1 5.9332	5.86875	11 1 0.0645	0.0153	0.0147	0.0173	6032	11 1 0.0639	6060	11 1 0.0665
67	9	16	39749	9023	11 1 21.9331	5.86875	11 1 16.0644	0.0152	0.0146	0.0172	6032	11 1 16.0638	6060	11 1 16.0664
67	9	16	39749	9023	11 1 37.9326	5.86875	11 1 32.0639	0.0151	0.0145	0.0171	6032	11 1 32.0633	6060	11 1 32.0659
67	9	16	39749	9023	11 1 53.9322	5.86875	11 1 48.0635	0.0149	0.0144	0.0170	6032	11 1 48.0630	6060	11 1 48.0656
67	9	16	39749	9023	11 2 9.9318	5.86875	11 2 4.0631	0.0148	0.0142	0.0169	6032	11 2 4.0625	6060	11 2 4.0652
67	9	16	39749	9023	11 2 25.9309	5.86875	11 2 20.0622	0.0147	0.0141	0.0168	6032	11 2 20.0616	6060	11 2 20.0643
67	9	16	39749	9023	11 2 41.9302	5.86875	11 2 36.0614	0.0146	0.0140	0.0168	6032	11 2 36.0608	6060	11 2 36.0636
67	9	16	39749	9023	11 2 57.9291	5.86875	11 2 52.0603	0.0145	0.0139	0.0167	6032	11 2 52.0597	6060	11 2 52.0625
67	11	18	39812	9023	17 41 48.1895	6.03110	17 41 42.1584	0.0108	0.0140	0.0114	6032	17 41 42.1616	6060	17 41 42.1590
67	11	18	39812	9023	17 41 56.1892	6.03110	17 41 50.1581	0.0107	0.0140	0.0113	6032	17 41 50.1614	6060	17 41 50.1587
67	11	18	39812	9023	17 42 4.1891	6.03110	17 41 58.1580	0.0106	0.0139	0.0112	6032	17 41 58.1613	6060	17 41 58.1586
67	11	18	39812	9023	17 42 12.1889	6.03110	17 42 6.1578	0.0105	0.0138	0.0112	6032	17 42 6.1611	6060	17 42 6.1585
67	11	18	39812	9023	17 42 20.1885	6.03110	17 42 14.1574	0.0104	0.0137	0.0111	6032	17 42 14.1607	6060	17 42 14.1581
67	11	18	39812	9023	17 42 28.1883	6.03110	17 42 22.1572	0.0104	0.0137	0.0110	6032	17 42 22.1605	6060	17 42 22.1578
67	11	18	39812	9023	17 42 36.1877	6.03110	17 42 30.1566	0.0103	0.0136	0.0109	6032	17 42 30.1599	6060	17 42 30.1572
67	11	19	39813	9023	17 45 2.3820	6.03388	17 44 56.3481	0.0098	0.0128	0.0108	6032	17 44 56.3511	6060	17 44 56.3491
67	11	19	39813	9023	17 45 10.3817	6.03388	17 45 4.3478	0.0097	0.0128	0.0108	6032	17 45 4.3509	6060	17 45 4.3489
67	11	19	39813	9023	17 45 18.3811	6.03388	17 45 12.3472	0.0097	0.0127	0.0107	6032	17 45 12.3502	6060	17 45 12.3482
67	11	19	39813	9023	17 45 26.3806	6.03388	17 45 20.3467	0.0096	0.0127	0.0107	6032	17 45 20.3498	6060	17 45 20.3478
67	11	19	39813	9023	17 45 34.3804	6.03388	17 45 28.3465	0.0096	0.0126	0.0106	6032	17 45 28.3495	6060	17 45 28.3475
67	11	19	39813	9023	17 45 42.3799	6.03388	17 45 36.3460	0.0095	0.0126	0.0106	6032	17 45 36.3491	6060	17 45 36.3471
67	11	19	39813	9023	17 45 50.3797	6.03388	17 45 44.3458	0.0095	0.0126	0.0106	6032	17 45 44.3489	6060	17 45 44.3469
67	11	20	39814	9023	17 48 57.9871	6.03667	17 48 51.9504	0.0092	0.0119	0.0106	6032	17 48 51.9531	6060	17 48 51.9518
67	11	20	39814	9023	17 49 5.9867	6.03667	17 48 59.9500	0.0092	0.0119	0.0106	6032	17 48 59.9527	6060	17 48 59.9514
67	11	20	39814	9023	17 49 13.9865	6.03667	17 49 7.9498	0.0092	0.0119	0.0106	6032	17 49 7.9525	6060	17 49 7.9512
67	11	27	39821	9023	15 0 41.6169	6.05555	15 0 35.5613	0.0158	0.0222	0.0124	6032	15 0 35.5677	6060	15 0 35.5579
67	11	27	39821	9023	15 0 57.6172	6.05555	15 0 51.5616	0.0158	0.0221	0.0125	6032	15 0 51.5679	6060	15 0 51.5583
67	11	27	39821	9023	15 1 13.6170	6.05555	15 1 7.5614	0.0156	0.0221	0.0125	6032	15 1 7.5677	6060	15 1 7.5581
67	12	3	39827	9023	15 5 9.1696	6.07134	15 5 3.0983	0.0154	0.0214	0.0126	6032	15 5 3.1043	6060	15 5 3.0955
67	12	3	39827	9023	15 5 25.1692	6.07134	15 5 19.0979	0.0153	0.0213	0.0125	6032	15 5 19.1039	6060	15 5 19.0951
67	12	3	39827	9023	15 5 41.1695	6.07135	15 5 35.0982	0.0151	0.0212	0.0123	6032	15 5 35.1043	6060	15 5 35.0954
67	12	3	39827	9023	15 5 57.1680	6.07135	15 5 51.0967	0.0150	0.0211	0.0122	6032	15 5 51.1028	6060	15 5 51.0939
69	5	4	40345	9023	10 17 10.6687	7.41095	10 17 3.2577	0.0141	0.0179	0.0130	6032	10 17 3.2615	6060	10 17 3.2566
69	5	4	40345	9023	10 17 26.6683	7.41095	10 17 19.2573	0.0140	0.0179	0.0128	6032	10 17 19.2612	6060	10 17 19.2561
69	5	4	40345	9023	10 17 42.6676	7.41095	10 17 35.2566	0.0138	0.0178	0.0126	6032	10 17 35.2606	6060	10 17 35.2554
69	5	4	40345	9023	10 17 58.6674	7.41095	10 17 51.2564	0.0136	0.0178	0.0123	6032	10 17 51.2606	6060	10 17 51.2551
69	5	24	40365	9023	9 48 7.6487	7.46667	9 48 0.1820	0.0113	0.0141	0.0116	6032	9 48 0.1848	6060	9 48 0.1823
69	5	24	40365	9023	9 48 15.6483	7.46667	9 48 8.1816	0.0112	0.0140	0.0115	6032	9 48 8.1844	6060	9 48 8.1819
69	5	24	40365	9023	9 48 23.6481	7.46668	9 48 16.1814	0.0111	0.0140	0.0114	6032	9 48 16.1843	6060	9 48 16.1817
69	5	24	40365	9023	9 48 31.6476	7.46668	9 48 24.1809	0.0110	0.0139	0.0112	6032	9 48 24.1838	6060	9 48 24.1811
69	5	24	40365	9023	9 48 39.6472	7.46668	9 48 32.1805	0.0109	0.0139	0.0111	6032	9 48 32.1835	6060	9 48 32.1807
69	5	24	40365	9023	9 48 47.6472	7.46668	9 48 40.1805	0.0108	0.0138	0.0110	6032	9 48 40.1835	6060	9 48 40.1807
69	5	24	40365	9023	9 49 3.6465	7.46668	9 48 56.1798	0.0106	0.0138	0.0108	6032	9 48 56.1830	6060	9 48 56.1800

Table 2.1-5 cont.

DATE YR	MO	DY	MJD	SAO NO	(AS) HR	MI	SEC	AS-UT1	(UT1) HR	MI	SEC	R/C SAO-SAT	R/C BC4-SAT	R/C BC4-SAT	BC4 NO	(UT1) HR	MI	SEC	BC4 NO	(UT1) HR	MI	SEC
69	6	7	40379	9023	9	26	8.1054	7.50362	9	26	0.6018	0.0114	0.0124	0.0129	6032	9	26	0.6028	6060	9	26	0.6033
69	6	7	40379	9023	9	26	16.1055	7.50362	9	26	8.6019	0.0113	0.0124	0.0128	6032	9	26	8.6030	6060	9	26	8.6034
69	6	7	40379	9023	9	26	24.1058	7.50362	9	26	16.6022	0.0112	0.0123	0.0127	6032	9	26	16.6033	6060	9	26	16.6037
69	6	7	40379	9023	9	26	32.1059	7.50362	9	26	24.6023	0.0111	0.0122	0.0126	6032	9	26	24.6034	6060	9	26	24.6038
69	6	7	40379	9023	9	26	40.1058	7.50362	9	26	32.6022	0.0110	0.0121	0.0125	6032	9	26	32.6033	6060	9	26	32.6037
69	6	7	40379	9023	9	26	48.1059	7.50363	9	26	40.6023	0.0109	0.0121	0.0124	6032	9	26	40.6035	6060	9	26	40.6038
69	6	7	40379	9023	9	26	56.1060	7.50363	9	26	48.6024	0.0108	0.0120	0.0123	6032	9	26	48.6036	6060	9	26	48.6039
69	6	7	40379	9023	9	27	4.1060	7.50363	9	26	56.6024	0.0107	0.0119	0.0123	6032	9	26	56.6036	6060	9	26	56.6040
69	6	23	40395	9023	20	31	7.9951	7.54294	20	31	0.4522	0.0116	0.0139	0.0122	6032	20	31	0.4545	6060	20	31	0.4528
69	6	23	40395	9023	20	31	15.9951	7.54294	20	31	8.4522	0.0116	0.0140	0.0123	6032	20	31	8.4546	6060	20	31	8.4529
69	6	23	40395	9023	20	31	23.9950	7.54294	20	31	16.4521	0.0117	0.0140	0.0124	6032	20	31	16.4544	6060	20	31	16.4528
69	6	23	40395	9023	20	31	31.9950	7.54294	20	31	24.4521	0.0118	0.0141	0.0125	6032	20	31	24.4544	6060	20	31	24.4528
69	6	23	40395	9023	20	31	39.9949	7.54294	20	31	32.4520	0.0119	0.0142	0.0125	6032	20	31	32.4543	6060	20	31	32.4526
69	6	23	40395	9023	20	31	47.9948	7.54294	20	31	40.4519	0.0120	0.0142	0.0126	6032	20	31	40.4541	6060	20	31	40.4525
69	6	23	40395	9023	20	31	55.9945	7.54294	20	31	48.4516	0.0121	0.0143	0.0127	6032	20	31	48.4538	6060	20	31	48.4522
69	6	23	40395	9023	20	32	3.9944	7.54294	20	31	56.4515	0.0122	0.0143	0.0128	6032	20	31	56.4536	6060	20	31	56.4521
69	7	7	40409	9023	17	3	28.3777	7.57129	17	3	20.8064	0.0162	0.0225	0.0128	6032	17	3	20.8127	6060	17	3	20.8030
69	7	7	40409	9022	17	3	44.3779	7.57129	17	3	36.8066	0.0162	0.0224	0.0128	6032	17	3	36.8128	6060	17	3	36.8032
69	7	7	40409	9023	17	4	0.3770	7.57129	17	3	52.8057	0.0161	0.0223	0.0128	6032	17	3	52.8119	6060	17	3	52.8024
69	7	8	40410	9023	17	0	10.8806	7.57324	17	0	3.3074	0.0164	0.0228	0.0128	6032	17	0	3.3138	6060	17	0	3.3038
69	7	8	40410	9023	17	0	26.8812	7.57324	17	0	19.3080	0.0163	0.0227	0.0127	6032	17	0	19.3144	6060	17	0	19.3044
69	7	8	40410	9023	17	0	42.8816	7.57324	17	0	35.3084	0.0162	0.0226	0.0127	6032	17	0	35.3148	6060	17	0	35.3049
69	7	8	40410	9023	17	0	58.8811	7.57324	17	0	51.3079	0.0161	0.0225	0.0126	6032	17	0	51.3143	6060	17	0	51.3044
69	7	8	40410	9023	19	51	44.8149	7.57347	19	51	37.2414	0.0155	0.0157	0.0174	6032	19	51	37.2416	6060	19	51	37.2433
69	7	8	40410	9023	19	52	0.8147	7.57347	19	51	53.2412	0.0152	0.0155	0.0172	6032	19	51	53.2415	6060	19	51	53.2432
69	7	8	40410	9023	19	52	16.8143	7.57347	19	52	9.2408	0.0150	0.0153	0.0170	6032	19	52	9.2411	6060	19	52	9.2428
69	7	8	40410	9023	19	52	32.8139	7.57347	19	52	25.2404	0.0148	0.0150	0.0168	6032	19	52	25.2406	6060	19	52	25.2424
69	7	8	40410	9023	19	52	48.8137	7.57347	19	52	41.2402	0.0146	0.0148	0.0166	6032	19	52	41.2404	6060	19	52	41.2422
69	7	8	40410	9023	19	53	4.8138	7.57347	19	52	57.2403	0.0143	0.0146	0.0164	6032	19	52	57.2406	6060	19	52	57.2424
69	7	8	40410	9023	19	53	20.8137	7.57347	19	53	13.2402	0.0141	0.0144	0.0162	6032	19	53	13.2405	6060	19	53	13.2423
69	7	15	40417	9023	19	44	20.0163	7.58684	19	44	12.4295	0.0129	0.0116	0.0158	6032	19	44	12.4282	6060	19	44	12.4324
69	7	15	40417	9023	19	44	36.0143	7.58684	19	44	28.4275	0.0127	0.0114	0.0156	6032	19	44	28.4262	6060	19	44	28.4304
69	7	15	40417	9023	19	44	52.0130	7.58684	19	44	44.4262	0.0125	0.0112	0.0155	6032	19	44	44.4249	6060	19	44	44.4292
69	7	15	40417	9023	19	45	8.0118	7.58684	19	45	0.4250	0.0123	0.0111	0.0153	6032	19	45	0.4238	6060	19	45	0.4280
69	7	15	40417	9023	19	45	24.0109	7.58684	19	45	16.4241	0.0122	0.0109	0.0152	6032	19	45	16.4228	6060	19	45	16.4271
69	7	15	40417	9023	19	45	40.0098	7.58684	19	45	32.4230	0.0120	0.0107	0.0150	6032	19	45	32.4217	6060	19	45	32.4260
69	7	15	40417	9023	19	45	56.0101	7.58684	19	45	48.4233	0.0119	0.0105	0.0149	6032	19	45	48.4219	6060	19	45	48.4263
69	7	20	40422	9023	19	42	14.8181	7.59661	19	42	7.2215	0.0111	0.0087	0.0145	6032	19	42	7.2191	6060	19	42	7.2249
69	7	20	40422	9023	19	42	22.8178	7.59661	19	42	15.2212	0.0111	0.0087	0.0145	6032	19	42	15.2188	6060	19	47	15.2246
69	7	20	40422	9023	19	42	30.8176	7.59661	19	47	23.2210	0.0111	0.0087	0.0144	6032	19	42	23.2186	6060	19	42	23.2243
69	7	20	40422	9023	19	42	38.8174	7.59661	19	42	31.2208	0.0111	0.0088	0.0144	6032	19	42	31.2185	6060	19	42	31.2241
69	7	20	40422	9023	19	42	46.8171	7.59661	19	42	39.2205	0.0111	0.0088	0.0144	6032	19	42	39.2182	6060	19	42	39.2238
69	7	20	40422	9023	19	42	54.8168	7.59661	19	42	47.2202	0.0111	0.0088	0.0144	6032	19	42	47.2179	6060	19	42	47.2235
69	7	20	40422	9023	19	43	2.8168	7.59661	19	42	55.2202	0.0111	0.0088	0.0144	6032	19	42	55.2179	6060	19	42	55.2235
69	7	22	40424	9023	19	30	53.1924	7.60044	19	30	45.5920	0.0151	0.0127	0.0183	6032	19	30	45.5896	6060	19	30	45.5952
69	7	22	40424	9023	19	31	9.1915	7.60044	19	31	1.5911	0.0149	0.0125	0.0181	6032	19	31	1.5887	6060	19	31	1.5943
69	7	22	40424	9023	19	31	25.1900	7.60044	19	31	17.5896	0.0148	0.0123	0.0179	6032	19	31	17.5871	6060	19	31	17.5927
69	7	22	40424	9023	19	31	57.1891	7.60044	19	31	49.5887	0.0144	0.0118	0.0176	6032	19	31	49.5861	6060	19	31	49.5919
69	7	22	40424	9023	19	32	13.1889	7.60044	19	32	5.5885	0.0142	0.0116	0.0174	6032	19	32	5.5859	6060	19	32	5.5917
69	9	15	40479	9023	16	7	27.0883	7.72213	16	7	19.3662	0.0171	0.0147	0.0196	6032	16	7	19.3638	6060	16	7	19.3687
69	9	15	40479	9023	16	7	43.0885	7.72213	16	7	35.3664	0.0172	0.0149	0.0197	6032	16	7	35.3641	6060	16	7	35.3689
69	9	15	40479	9023	16	7	59.0893	7.72213	16	7	51.3672	0.0174	0.0152	0.0198	6032	16	7	51.3650	6060	16	7	51.3696
69	9	15	40479	9023	16	8	15.0896	7.72213	16	8	7.3675	0.0175	0.0154	0.0200	6032	16	8	7.3654	6060	16	8	7.3700
69	9	15	40479	9023	16	8	31.0906	7.72213	16	8	23.3685	0.0177	0.0156	0.0201	6032	16	8	23.3664	6060	16	8	23.3709
69	9	15	40479	9023	16	8	47.0916	7.72213	16	8	39.3695	0.0179	0.0158	0.0202	6032	16	8	39.3674	6060	16	8	39.3718
69	9	15	40479	9023	16	9	3.0929	7.72213	16	8	55.3708	0.0180	0.0161	0.0203	6032	16	8	55.3689	6060	16	8	55.3731
69	9	20	40484	9023	13	4	18.2476	7.73618	13	4	10.5114	0.0141	0.0172	0.0138	6032	13	4	10.5145	6060	13	4	10.5111
69	9	20	40484	9023	13	4	34.2475	7.73618	13	4	26.5113	0.0143	0.0174	0.0140	6032	13	4	26.5144	6060	13	4	26.5110
69	9	20	40484	9023	13	4	50.2473	7.73619	13	4	42.5111	0.0145	0.0175	0.0143	6032	13	4	42.5141	6060	13	4	42.5109

Table 2.1-5 cont.

DATE YR	MO	DY	MJD	SAO NO	(AS) HR	MI	SEC	AS-UT1	(UT1) HR	MI	SEC	R/C SAO-SAT	R/C BC4-SAT	R/C BC4-SAT	BC4 NO	(UT1) HR	MI	SEC	BC4 NO	(UT1) HR	MI	SEC
69	9	20	40484	9023	13	5	6.2469	7.73619	13	4	58.5107	0.0147	0.0177	0.0145	6032	13	4	58.5137	6060	13	4	58.5105
69	9	20	40484	9023	13	5	22.2463	7.73619	13	5	14.5101	0.0149	0.0178	0.0147	6032	13	5	14.5130	6060	13	5	14.5099
69	9	23	40487	9023	16	2	9.0880	7.74525	16	2	1.3428	0.0181	0.0140	0.0213	6032	16	2	1.3387	6060	16	2	1.3460
69	9	23	40487	9023	16	2	25.0861	7.74525	16	2	17.3409	0.0181	0.0142	0.0214	6032	16	2	17.3370	6060	16	2	17.3442
69	9	23	40487	9023	16	2	41.0841	7.74525	16	2	33.3389	0.0182	0.0143	0.0214	6032	16	2	33.3350	6060	16	2	33.3421
69	9	23	40487	9023	16	2	57.0826	7.74525	16	2	49.3374	0.0183	0.0145	0.0215	6032	16	2	49.3336	6060	16	2	49.3406
69	9	27	40491	9023	13	2	53.7917	7.75641	13	2	46.0353	0.0156	0.0175	0.0160	6032	13	2	46.0372	6060	13	2	46.0357
69	9	27	40491	9023	13	3	9.7907	7.75641	13	3	2.0343	0.0158	0.0177	0.0163	6032	13	3	2.0362	6060	13	3	2.0348
69	9	27	40491	9023	13	3	25.7899	7.75641	13	3	18.0335	0.0160	0.0179	0.0165	6032	13	3	18.0354	6060	13	3	18.0340
69	9	27	40491	9023	13	3	41.7886	7.75641	13	3	34.0322	0.0163	0.0181	0.0167	6032	13	3	34.0340	6060	13	3	34.0326
69	9	27	40491	9023	13	3	57.7873	7.75642	13	3	50.0309	0.0165	0.0183	0.0169	6032	13	3	50.0327	6060	13	3	50.0313
69	9	27	40491	9023	15	58	21.4595	7.75676	15	58	13.7027	0.0189	0.0141	0.0225	6032	15	58	13.6979	6060	15	58	13.7063
69	9	27	40491	9023	15	58	37.4593	7.75676	15	58	29.7025	0.0190	0.0142	0.0225	6032	15	58	29.6977	6060	15	58	29.7060
69	9	27	40491	9023	15	58	53.4596	7.75677	15	58	45.7028	0.0190	0.0143	0.0225	6032	15	58	45.6981	6060	15	58	45.7063
69	9	27	40491	9023	15	59	9.4603	7.75677	15	59	1.7035	0.0191	0.0144	0.0225	6032	15	59	1.6988	6060	15	59	1.7069
69	9	27	40491	9023	15	59	25.4607	7.75677	15	59	17.7039	0.0191	0.0146	0.0225	6032	15	59	17.6994	6060	15	59	17.7073
69	9	27	40491	9023	15	59	41.4616	7.75677	15	59	33.7048	0.0192	0.0147	0.0226	6032	15	59	33.7003	6060	15	59	33.7082
69	9	27	40491	9023	15	59	57.4625	7.75677	15	59	49.7057	0.0193	0.0149	0.0226	6032	15	59	49.7013	6060	15	59	49.7090
69	9	28	40492	9023	12	58	23.5797	7.75929	12	58	15.8204	0.0126	0.0150	0.0133	6032	12	58	15.8228	6060	12	58	15.8211
69	9	28	40492	9023	12	58	39.5790	7.75929	12	58	31.8197	0.0128	0.0151	0.0135	6032	12	58	31.8220	6060	12	58	31.8204
69	9	28	40492	9023	12	58	55.5783	7.75929	12	58	47.8190	0.0130	0.0153	0.0136	6032	12	58	47.8213	6060	12	58	47.8196
69	9	28	40492	9023	12	59	11.5776	7.75929	12	59	3.8183	0.0132	0.0154	0.0138	6032	12	59	3.8205	6060	12	59	3.8189
69	9	28	40492	9023	12	59	27.5764	7.75929	12	59	19.8171	0.0134	0.0156	0.0140	6032	12	59	19.8193	6060	12	59	19.8177
69	9	28	40492	9023	12	59	43.5757	7.75929	12	59	35.8164	0.0136	0.0157	0.0142	6032	12	59	35.8185	6060	12	59	35.8170
69	10	4	40498	9023	12	52	18.3309	7.77667	12	52	10.5542	0.0119	0.0133	0.0134	6032	12	52	10.5556	6060	12	52	10.5557
69	10	4	40498	9023	12	52	34.3304	7.77667	12	52	26.5537	0.0120	0.0135	0.0135	6032	12	52	26.5552	6060	12	52	26.5552
69	10	4	40498	9023	12	52	50.3297	7.77667	12	52	42.5530	0.0122	0.0136	0.0137	6032	12	52	42.5544	6060	12	52	42.5545
69	10	4	40498	9023	12	53	6.3289	7.77667	12	52	58.5522	0.0123	0.0137	0.0138	6032	12	52	58.5536	6060	12	52	58.5537
69	10	4	40498	9023	12	53	22.3282	7.77667	12	53	14.5515	0.0125	0.0139	0.0139	6032	12	53	14.5529	6060	12	53	14.5529
69	10	4	40498	9023	12	53	38.3274	7.77667	12	53	30.5507	0.0127	0.0140	0.0141	6032	12	53	30.5520	6060	12	53	30.5521
69	10	4	40498	9023	12	53	54.3266	7.77668	12	53	46.5499	0.0128	0.0142	0.0142	6032	12	53	46.5513	6060	12	53	46.5513
69	10	4	40498	9023	12	54	10.3260	7.77668	12	54	2.5493	0.0130	0.0143	0.0144	6032	12	54	2.5506	6060	12	54	2.5507
69	10	5	40499	9023	9	49	8.0742	7.77915	9	49	0.2951	0.0185	0.0246	0.0151	6032	9	49	0.3012	6060	9	49	0.2917
69	10	5	40499	9023	9	49	24.0757	7.77915	9	49	16.2966	0.0185	0.0246	0.0151	6032	9	49	16.3027	6060	9	49	16.2932
69	10	5	40499	9023	9	49	40.0769	7.77915	9	49	32.2977	0.0185	0.0246	0.0152	6032	9	49	32.3038	6060	9	49	32.2944
69	10	5	40499	9023	9	49	56.0776	7.77915	9	49	48.2984	0.0186	0.0246	0.0153	6032	9	49	48.3044	6060	9	49	48.2951
69	10	5	40499	9023	9	50	12.0783	7.77915	9	50	4.2991	0.0186	0.0246	0.0154	6032	9	50	4.3051	6060	9	50	4.2959
69	10	5	40499	9023	9	50	28.0786	7.77915	9	50	20.2994	0.0186	0.0246	0.0154	6032	9	50	20.3054	6060	9	50	20.2962
69	10	5	40499	9023	9	50	44.0785	7.77915	9	50	36.2993	0.0187	0.0246	0.0155	6032	9	50	36.3052	6060	9	50	36.2961
69	10	5	40499	9023	9	51	0.0783	7.77915	9	50	52.2991	0.0187	0.0246	0.0156	6032	9	50	52.3050	6060	9	50	52.2960
69	10	5	40499	9023	12	54	3.0094	7.77951	12	53	55.2299	0.0136	0.0147	0.0150	6032	12	53	55.2310	6060	12	53	55.2313
69	10	5	40499	9023	12	54	19.0085	7.77951	12	54	11.2290	0.0138	0.0148	0.0152	6032	12	54	11.2300	6060	12	54	11.2304
69	10	5	40499	9023	12	54	35.0079	7.77951	12	54	27.2284	0.0140	0.0150	0.0153	6032	12	54	27.2294	6060	12	54	27.2297
69	10	5	40499	9023	12	54	51.0070	7.77951	12	54	43.2275	0.0142	0.0152	0.0155	6032	12	54	43.2285	6060	12	54	43.2288
69	10	5	40499	9023	12	55	7.0060	7.77951	12	54	59.2265	0.0144	0.0154	0.0157	6032	12	54	59.2275	6060	12	54	59.2278
69	10	11	40505	9023	12	42	49.0024	7.79644	12	42	41.2060	0.0118	0.0118	0.0143	6032	12	42	41.2060	6060	12	42	41.2085
69	10	11	40505	9023	12	43	5.0013	7.79644	12	42	57.2049	0.0119	0.0119	0.0144	6032	12	42	57.2049	6060	12	42	57.2074
69	10	11	40505	9023	12	43	21.0003	7.79645	12	43	13.2039	0.0120	0.0120	0.0144	6032	12	43	13.2039	6060	12	43	13.2063
69	10	13	40507	9023	12	42	25.6893	7.80212	12	42	17.8872	0.0128	0.0124	0.0153	6032	12	42	17.8868	6060	12	42	17.8897
69	10	13	40507	9023	12	42	41.6883	7.80212	12	42	33.8862	0.0129	0.0125	0.0154	6032	12	42	33.8858	6060	12	42	33.8887
69	10	13	40507	9023	12	42	57.6868	7.80212	12	42	49.8847	0.0130	0.0126	0.0155	6032	12	42	49.8843	6060	12	42	49.8872
69	10	13	40507	9023	12	43	13.6854	7.80213	12	43	5.8833	0.0132	0.0127	0.0156	6032	12	43	5.8828	6060	12	43	5.8857
69	10	14	40508	9023	12	42	40.1768	7.80496	12	42	32.3718	0.0136	0.0130	0.0160	6032	12	42	32.3712	6060	12	42	32.3742
69	10	14	40508	9023	12	42	56.1776	7.80496	12	42	48.3726	0.0137	0.0131	0.0161	6032	12	42	48.3720	6060	12	42	48.3750
69	10	14	40508	9023	12	43	12.1949	7.80497	12	43	4.3899	0.0138	0.0133	0.0162	6032	12	43	4.3894	6060	12	43	4.3923
69	10	18	40512	9023	12	47	7.8601	7.81631	12	47	0.0438	0.0196	0.0191	0.0212	6032	12	47	0.0433	6060	12	47	0.0454
69	10	18	40512	9023	12	47	23.8597	7.81631	12	47	16.0434	0.0198	0.0193	0.0214	6032	12	47	16.0429	6060	12	47	16.0450
69	10	18	40512	9023	12	47	55.8589	7.81631	12	47	48.0426	0.0202	0.0197	0.0217	6032	12	47	48.0421	6060	12	47	48.0441
69	10	18	40512	9023	12	48	11.8584	7.81631	12	48	4.0421	0.0204	0.0199	0.0219	6032	12	48	4.0416	6060	12	48	4.0436

Table 2.1-5 cont.

DATE YR	MO	DY	MJD	SAO NO	(AS) HR	MI	SEC	AS-UT1	(UT1) HR	MI	SEC	R/C SAO-SAT	R/C BC4-SAT	R/C BC4-SAT	BC4 NO	(UT1) HR	MI	SEC	BC4 NO	(UT1) HR	MI	SEC
69	10	19	40513	9023	12	43	7.8703	7.81916	12	43	0.0511	0.0178	0.0169	0.0198	6032	12	43	0.0502	6060	12	43	0.0531
69	10	19	40513	9023	12	43	23.8696	7.81916	12	43	16.0504	0.0180	0.0171	0.0200	6032	12	43	16.0495	6060	12	43	16.0524
69	10	19	40513	9023	12	43	39.8691	7.81916	12	43	32.0499	0.0181	0.0173	0.0201	6032	12	43	32.0491	6060	12	43	32.0519
69	10	19	40513	9023	12	43	55.8685	7.81916	12	43	48.0493	0.0183	0.0175	0.0202	6032	12	43	48.0485	6060	12	43	48.0512
69	10	19	40513	9023	12	44	11.8681	7.81916	12	44	4.0489	0.0185	0.0177	0.0204	6032	12	44	4.0481	6060	12	44	4.0508
69	10	22	40516	9023	12	41	34.1395	7.82776	12	41	26.3117	0.0193	0.0182	0.0213	6032	12	41	26.3106	6060	12	41	26.3137
69	10	22	40516	9023	12	41	50.1384	7.82776	12	41	42.3106	0.0195	0.0184	0.0214	6032	12	41	42.3095	6060	12	41	42.3125
69	10	22	40516	9023	12	42	6.1373	7.82776	12	41	58.3095	0.0197	0.0186	0.0216	6032	12	41	58.3084	6060	12	41	58.3114
69	10	22	40516	9023	12	42	22.1362	7.82776	12	42	14.3084	0.0198	0.0188	0.0217	6032	12	42	14.3074	6060	12	42	14.3103
69	10	23	40517	9023	12	39	1.7218	7.83064	12	38	53.8912	0.0186	0.0172	0.0208	6032	12	38	53.8898	6060	12	38	53.8934
69	10	23	40517	9023	12	39	17.7208	7.83064	12	39	9.8902	0.0188	0.0174	0.0209	6032	12	39	9.8888	6060	12	39	9.8923
69	10	23	40517	9023	12	39	33.7198	7.83064	12	39	25.8892	0.0189	0.0176	0.0211	6032	12	39	25.8879	6060	12	39	25.8914
69	10	23	40517	9023	12	39	49.7190	7.83064	12	39	41.8884	0.0191	0.0178	0.0212	6032	12	39	41.8871	6060	12	39	41.8905
69	10	23	40517	9023	12	40	5.7184	7.83064	12	39	57.8878	0.0192	0.0180	0.0213	6032	12	39	57.8866	6060	12	39	57.8899
69	10	30	40524	9023	12	31	52.0309	7.85105	12	31	44.1799	0.0202	0.0180	0.0227	6032	12	31	44.1777	6060	12	31	44.1824
69	10	30	40524	9023	12	32	8.0303	7.85105	12	32	0.1792	0.0203	0.0182	0.0228	6032	12	32	0.1771	6060	12	32	0.1817
69	10	30	40524	9023	12	32	24.0305	7.85105	12	32	16.1794	0.0205	0.0184	0.0229	6032	12	32	16.1773	6060	12	32	16.1818
69	10	30	40524	9023	12	32	40.0308	7.85105	12	32	32.1797	0.0206	0.0186	0.0230	6032	12	32	32.1777	6060	12	32	32.1821
69	11	5	40530	9023	12	32	55.8828	7.86879	12	32	48.0140	0.0251	0.0237	0.0269	6032	12	32	48.0126	6060	12	32	48.0158
69	11	5	40530	9023	12	33	11.8827	7.86879	12	33	4.0139	0.0253	0.0238	0.0270	6032	12	33	4.0124	6060	12	33	4.0156
69	11	5	40530	9023	12	33	27.8825	7.86879	12	33	20.0137	0.0254	0.0240	0.0271	6032	12	33	20.0123	6060	12	33	20.0154
69	11	5	40530	9023	12	33	43.8827	7.86879	12	33	36.0139	0.0255	0.0242	0.0272	6032	12	33	36.0126	6060	12	33	36.0155
69	11	5	40530	9023	12	33	59.8828	7.86879	12	33	52.0140	0.0257	0.0244	0.0273	6032	12	33	52.0127	6060	12	33	52.0156
69	11	5	40530	9023	12	34	15.8830	7.86879	12	34	8.0142	0.0258	0.0246	0.0274	6032	12	34	8.0130	6060	12	34	8.0158
69	11	5	40530	9023	12	34	31.8833	7.86879	12	34	24.0145	0.0260	0.0247	0.0275	6032	12	34	24.0132	6060	12	34	24.0160
69	12	7	40562	9023	15	42	52.3147	7.96158	15	42	44.3531	0.0267	0.0312	0.0244	6032	15	42	44.3576	6060	15	42	44.3508
69	12	7	40562	9023	15	43	8.3151	7.96158	15	43	0.3535	0.0266	0.0312	0.0243	6032	15	43	0.3581	6060	15	43	0.3512
69	12	7	40562	9023	15	43	24.3149	7.96158	15	43	16.3533	0.0266	0.0312	0.0243	6032	15	43	16.3579	6060	15	43	16.3510
69	12	7	40562	9023	15	43	40.3146	7.96158	15	43	32.3530	0.0265	0.0312	0.0242	6032	15	43	32.3577	6060	15	43	32.3507
69	12	7	40562	9023	15	43	56.3145	7.96158	15	43	48.3529	0.0265	0.0312	0.0241	6032	15	43	48.3576	6060	15	43	48.3505
69	12	7	40562	9023	15	44	12.3145	7.96158	15	44	4.3529	0.0264	0.0312	0.0240	6032	15	44	4.3577	6060	15	44	4.3505
69	12	8	40563	9023	15	43	38.2442	7.96449	15	43	30.2797	0.0261	0.0309	0.0236	6032	15	43	30.2845	6060	15	43	30.2772
69	12	8	40563	9023	15	43	54.2440	7.96449	15	43	46.2795	0.0260	0.0309	0.0235	6032	15	43	46.2844	6060	15	43	46.2770
69	12	8	40563	9023	15	44	10.2441	7.96450	15	44	2.2796	0.0260	0.0309	0.0235	6032	15	44	2.2845	6060	15	44	2.2771
69	12	13	40568	9023	15	44	8.4276	7.97917	15	44	0.4484	0.0236	0.0292	0.0206	6032	15	44	0.4540	6060	15	44	0.4454
69	12	13	40568	9023	15	44	24.4275	7.97918	15	44	16.4483	0.0235	0.0292	0.0205	6032	15	44	16.4540	6060	15	44	16.4453
69	12	13	40568	9023	15	44	40.4271	7.97918	15	44	32.4479	0.0235	0.0292	0.0205	6032	15	44	32.4536	6060	15	44	32.4449
69	12	13	40568	9023	15	44	56.4270	7.97918	15	44	48.4478	0.0234	0.0292	0.0204	6032	15	44	48.4536	6060	15	44	48.4448
69	12	13	40568	9023	15	45	12.4268	7.97918	15	45	4.4476	0.0234	0.0293	0.0203	6032	15	45	4.4535	6060	15	45	4.4445
69	12	13	40568	9023	18	32	8.6737	7.97952	18	32	0.6942	0.0227	0.0232	0.0237	6032	18	32	0.6947	6060	18	32	0.6952
69	12	13	40568	9023	18	32	24.6741	7.97952	18	32	16.6946	0.0225	0.0230	0.0235	6032	18	32	16.6951	6060	18	32	16.6956
69	12	13	40568	9023	18	32	40.6747	7.97952	18	32	32.6952	0.0224	0.0229	0.0234	6032	18	32	32.6957	6060	18	32	32.6962
69	12	13	40568	9023	18	32	56.6137	7.97952	18	32	48.6342	0.0222	0.0228	0.0232	6032	18	32	48.6348	6060	18	32	48.6352
69	12	13	40568	9023	18	33	12.6737	7.97952	18	33	4.6942	0.0221	0.0226	0.0231	6032	18	33	4.6947	6060	18	33	4.6952
69	12	14	40569	9023	15	43	52.2082	7.98220	15	43	44.2260	0.0231	0.0289	0.0201	6032	15	43	44.2318	6060	15	43	44.2230
69	12	14	40569	9023	15	44	8.2077	7.98220	15	44	0.2255	0.0231	0.0289	0.0200	6032	15	44	0.2313	6060	15	44	0.2224
69	12	14	40569	9023	15	44	24.2072	7.98220	15	44	16.2250	0.0231	0.0289	0.0200	6032	15	44	16.2308	6060	15	44	16.2219
69	12	14	40569	9023	15	44	40.2069	7.98220	15	44	32.2247	0.0230	0.0289	0.0199	6032	15	44	32.2306	6060	15	44	32.2216
69	12	14	40569	9023	15	44	56.2067	7.98220	15	44	48.2245	0.0230	0.0289	0.0199	6032	15	44	48.2304	6060	15	44	48.2214
69	12	15	40570	9023	18	34	55.7157	7.98560	18	34	47.7301	0.0198	0.0204	0.0210	6032	18	34	47.7307	6060	18	34	47.7313
69	12	15	40570	9023	18	35	11.7156	7.98560	18	35	3.7300	0.0197	0.0203	0.0209	6032	18	35	3.7306	6060	18	35	3.7312
69	12	15	40570	9023	18	35	27.7156	7.98561	18	35	19.7300	0.0195	0.0202	0.0208	6032	18	35	19.7307	6060	18	35	19.7313
69	12	15	40570	9023	18	35	43.7155	7.98561	18	35	35.7299	0.0194	0.0201	0.0206	6032	18	35	35.7306	6060	18	35	35.7311
69	12	15	40570	9023	18	35	59.7158	7.98561	18	35	51.7302	0.0193	0.0199	0.0205	6032	18	35	51.7308	6060	18	35	51.7314
69	12	15	40570	9023	18	36	15.7157	7.98561	18	36	7.7301	0.0191	0.0198	0.0204	6032	18	36	7.7308	6060	18	36	7.7314
69	12	16	40571	9023	15	43	52.0604	7.98827	15	43	44.0721	0.0222	0.0282	0.0190	6032	15	43	44.0781	6060	15	43	44.0689
69	12	16	40571	9023	15	44	8.0598	7.98827	15	44	0.0715	0.0222	0.0283	0.0190	6032	15	44	0.0776	6060	15	44	0.0683
69	12	16	40571	9023	15	44	24.0591	7.98827	15	44	16.0708	0.0222	0.0283	0.0189	6032	15	44	16.0769	6060	15	44	16.0675
69	12	16	40571	9023	15	44	40.0588	7.98827	15	44	32.0705	0.0221	0.0283	0.0189	6032	15	44	32.0767	6060	15	44	32.0673

Table 2.1-5 cont.

DATE YR	MO	DY	MJD	SAO NO	(AS) HR	MI	SEC	AS-UT1	(UT1) HR	MI	SEC	R/C SAO-SAT	R/C BC4-SAT	R/C BC4-SAT	BC4 NO	(UT1) HR	MI	SEC	BC4 NO	(UT1) HR	MI	SEC
69	12	16	40571	9023	15	44	56.0583	7.98827	15	44	48.0700	0.0221	0.0283	0.0189	6032	15	44	48.0762	6060	15	44	48.0668
69	12	16	40571	9023	15	45	12.0581	7.98827	15	45	4.0698	0.0221	0.0283	0.0188	6032	15	45	4.0760	6060	15	45	4.0665
69	12	16	40571	9023	18	33	7.7167	7.98862	18	32	59.7281	0.0202	0.0206	0.0214	6032	18	32	59.7285	6060	18	32	59.7293
69	12	16	40571	9023	18	33	23.7169	7.98862	18	33	15.7283	0.0200	0.0205	0.0213	6032	18	33	15.7288	6060	18	33	15.7296
69	12	16	40571	9023	18	33	39.7169	7.98862	18	33	31.7283	0.0199	0.0204	0.0212	6032	18	33	31.7288	6060	18	33	31.7296
69	12	16	40571	9023	18	33	55.7163	7.98863	18	33	47.7277	0.0197	0.0202	0.0210	6032	18	33	47.7282	6060	18	33	47.7290
69	12	16	40571	9023	18	34	11.7166	7.98863	18	34	3.7280	0.0196	0.0201	0.0209	6032	18	34	3.7285	6060	18	34	3.7293
69	12	21	40576	9023	18	24	7.3095	8.00343	18	23	59.3061	0.0221	0.0218	0.0235	6032	18	23	59.3058	6060	18	23	59.3075
69	12	21	40576	9023	18	24	23.3094	8.00343	18	24	15.3060	0.0219	0.0217	0.0234	6032	18	24	15.3058	6060	18	24	15.3075
69	12	21	40576	9023	18	24	39.3093	8.00344	18	24	31.3059	0.0218	0.0215	0.0232	6032	18	24	31.3056	6060	18	24	31.3073
69	12	21	40576	9023	18	24	55.3094	8.00344	18	24	47.3060	0.0216	0.0214	0.0231	6032	18	24	47.3058	6060	18	24	47.3075
69	12	21	40576	9023	18	25	11.3094	8.00344	18	25	3.3060	0.0214	0.0212	0.0229	6032	18	25	3.3058	6060	18	25	3.3075
69	12	23	40578	9023	18	25	55.7087	8.00932	18	25	47.6994	0.0197	0.0193	0.0215	6032	18	25	47.6990	6060	18	25	47.7012
69	12	23	40578	9023	18	26	11.7090	8.00932	18	26	3.6997	0.0196	0.0192	0.0213	6032	18	26	3.6993	6060	18	26	3.7014
69	12	23	40578	9023	18	26	27.7090	8.00932	18	26	19.6997	0.0194	0.0190	0.0212	6032	18	26	19.6993	6060	18	26	19.7015
69	12	23	40578	9023	18	26	43.7088	8.00932	18	26	35.6995	0.0193	0.0189	0.0211	6032	18	26	35.6991	6060	18	26	35.7013
69	12	23	40578	9023	18	26	59.7089	8.00932	18	26	51.6996	0.0191	0.0188	0.0210	6032	18	26	51.6993	6060	18	26	51.7015
69	12	23	40578	9023	18	27	15.7081	8.00932	18	27	7.6988	0.0190	0.0186	0.0208	6032	18	27	7.6984	6060	18	27	7.7006
69	12	27	40582	9023	15	35	7.4367	8.02074	15	34	59.4160	0.0184	0.0246	0.0154	6032	15	34	59.4222	6060	15	34	59.4130
69	12	27	40582	9023	15	35	23.4360	8.02074	15	35	15.4153	0.0184	0.0246	0.0154	6032	15	35	15.4215	6060	15	35	15.4123
69	12	27	40582	9023	15	35	39.4358	8.02074	15	35	31.4151	0.0184	0.0246	0.0154	6032	15	35	31.4213	6060	15	35	31.4121
69	12	27	40582	9023	15	35	55.4354	8.02074	15	35	47.4147	0.0184	0.0247	0.0154	6032	15	35	47.4210	6060	15	35	47.4117
69	12	27	40582	9023	15	36	11.4352	8.02074	15	36	3.4145	0.0185	0.0247	0.0154	6032	15	36	3.4207	6060	15	36	3.4114
69	12	27	40582	9023	18	27	54.0566	8.02109	18	27	46.0355	0.0166	0.0156	0.0191	6032	18	27	46.0345	6060	18	27	46.0380
69	12	27	40582	9023	18	28	10.0565	8.02109	18	28	2.0354	0.0165	0.0155	0.0190	6032	18	28	2.0344	6060	18	28	2.0379
69	12	27	40582	9023	18	28	26.0566	8.02109	18	28	18.0355	0.0164	0.0154	0.0189	6032	18	28	18.0345	6060	18	28	18.0380
69	12	27	40582	9023	18	28	42.0563	8.02109	18	28	34.0352	0.0163	0.0153	0.0188	6032	18	28	34.0342	6060	18	28	34.0377
69	12	27	40582	9023	18	28	58.0556	8.02109	18	28	50.0345	0.0162	0.0152	0.0188	6032	18	28	50.0335	6060	18	28	50.0371
69	12	27	40582	9023	18	29	14.0550	8.02109	18	29	6.0339	0.0161	0.0151	0.0187	6032	18	29	6.0329	6060	18	29	6.0365
69	12	28	40583	9023	15	31	4.6070	8.02366	15	30	56.5833	0.0182	0.0241	0.0155	6032	15	30	56.5892	6060	15	30	56.5806
69	12	28	40583	9023	15	31	20.6065	8.02366	15	31	12.5828	0.0182	0.0241	0.0155	6032	15	31	12.5887	6060	15	31	12.5801
69	12	28	40583	9023	15	31	36.6062	8.02367	15	31	28.5825	0.0182	0.0241	0.0154	6032	15	31	28.5884	6060	15	31	28.5797
69	12	28	40583	9023	15	31	52.6060	8.02367	15	31	44.5823	0.0182	0.0241	0.0154	6032	15	31	44.5882	6060	15	31	44.5795
69	12	28	40583	9023	15	32	8.6059	8.02367	15	32	0.5822	0.0181	0.0241	0.0154	6032	15	32	0.5882	6060	15	32	0.5795
69	12	29	40584	9023	18	14	53.8431	8.02694	18	14	45.8162	0.0225	0.0215	0.0242	6032	18	14	45.8152	6060	18	14	45.8179
69	12	29	40584	9023	18	15	9.8433	8.02694	18	15	1.8164	0.0223	0.0213	0.0241	6032	18	15	1.8154	6060	18	15	1.8182
69	12	29	40584	9023	18	15	25.8433	8.02694	18	15	17.8164	0.0221	0.0211	0.0239	6032	18	15	17.8154	6060	18	15	17.8182
69	12	29	40584	9023	18	15	41.8433	8.02694	18	15	33.8164	0.0220	0.0209	0.0238	6032	18	15	33.8153	6060	18	15	33.8182
69	12	29	40584	9023	18	15	57.8430	8.02694	18	15	49.8161	0.0218	0.0208	0.0236	6032	18	15	49.8151	6060	18	15	49.8179
69	12	29	40584	9023	18	16	13.8427	8.02694	18	16	5.8158	0.0216	0.0206	0.0235	6032	18	16	5.8148	6060	18	16	5.8177
69	12	30	40585	9023	15	33	56.8758	8.02955	15	33	48.8463	0.0176	0.0237	0.0147	6032	15	33	48.8524	6060	15	33	48.8434
69	12	30	40585	9023	15	34	12.8889	8.02955	15	34	4.8594	0.0176	0.0238	0.0147	6032	15	34	4.8656	6060	15	34	4.8565
69	12	30	40585	9023	15	34	28.8881	8.02955	15	34	20.8586	0.0177	0.0238	0.0148	6032	15	34	20.8647	6060	15	34	20.8557
69	12	30	40585	9023	15	34	44.8877	8.02955	15	34	36.8582	0.0177	0.0239	0.0148	6032	15	34	36.8644	6060	15	34	36.8553
69	12	30	40585	9023	15	35	0.8869	8.02955	15	34	52.8574	0.0178	0.0239	0.0148	6032	15	34	52.8635	6060	15	34	52.8544
69	12	30	40585	9023	15	35	16.8863	8.02955	15	35	8.8568	0.0178	0.0240	0.0149	6032	15	35	8.8630	6060	15	35	8.8539
69	12	30	40585	9023	18	24	52.2691	8.02989	18	24	44.2392	0.0167	0.0152	0.0194	6032	18	24	44.2377	6060	18	24	44.2419
69	12	30	40585	9023	18	25	8.2694	8.02990	18	25	0.2395	0.0166	0.0150	0.0193	6032	18	25	0.2379	6060	18	25	0.2422
69	12	30	40585	9023	18	25	24.2700	8.02990	18	25	16.2401	0.0165	0.0149	0.0193	6032	18	25	16.2385	6060	18	25	16.2429
69	12	30	40585	9023	18	25	40.2698	8.02990	18	25	32.2399	0.0164	0.0148	0.0192	6032	18	25	32.2383	6060	18	25	32.2427
69	12	30	40585	9023	18	25	56.2697	8.02990	18	25	48.2398	0.0163	0.0147	0.0191	6032	18	25	48.2382	6060	18	25	48.2426
69	12	30	40585	9023	18	26	12.2696	8.02990	18	26	4.2397	0.0163	0.0146	0.0190	6032	18	26	4.2380	6060	18	26	4.2424
70	1	4	40590	9023	15	29	52.1893	8.04400	15	29	44.1453	0.0161	0.0220	0.0136	6032	15	29	44.1512	6060	15	29	44.1428
70	1	4	40590	9023	15	30	8.1887	8.04400	15	30	0.1447	0.0162	0.0220	0.0137	6032	15	30	0.1505	6060	15	30	0.1422
70	1	4	40590	9023	15	30	24.1880	8.04400	15	30	16.1440	0.0162	0.0221	0.0137	6032	15	30	16.1499	6060	15	30	16.1415
70	1	4	40590	9023	15	30	40.1872	8.04400	15	30	32.1432	0.0163	0.0221	0.0138	6032	15	30	32.1490	6060	15	30	32.1407
70	1	4	40590	9023	15	30	56.1872	8.04400	15	30	48.1432	0.0163	0.0222	0.0138	6032	15	30	48.1491	6060	15	30	48.1407
70	1	4	40590	9023	15	31	12.1866	8.04400	15	31	4.1426	0.0164	0.0223	0.0139	6032	15	31	4.1485	6060	15	31	4.1401
70	1	5	40591	9023	15	30	56.6548	8.04686	15	30	48.6079	0.0167	0.0220	0.0138	6032	15	30	48.6137	6060	15	30	48.6055

Table 2.1-5 cont.

DATE YR	MO	DY	MJD	SAO NO	(AS) HR	MI	SEC	AS-UT1	(UT1) HR	MI	SEC	R/C SAO-SAT	R/C BC4-SAT	R/C BC4-SAT	BC4 NO	(UT1) HR	MI	SEC	BC4 NO	(UT1) HR	MI	SEC
70	1	5	40591	9023	15	31	12.6544	8.04686	15	31	4.6075	0.0162	0.0220	0.0138	6032	15	31	4.6133	6060	15	31	4.6051
70	1	5	40591	9023	15	31	28.6545	8.04686	15	31	20.6076	0.0163	0.0221	0.0139	6032	15	31	20.6134	6060	15	31	20.6052
70	1	11	40597	9023	15	23	4.0361	8.06411	15	22	55.9720	0.0139	0.0190	0.0124	6032	15	22	55.9771	6060	15	22	55.9705
70	1	11	40597	9023	15	23	20.0357	8.06411	15	23	11.9716	0.0139	0.0191	0.0124	6032	15	23	11.9768	6060	15	23	11.9701
70	1	11	40597	9023	15	23	36.0358	8.06411	15	23	27.9717	0.0139	0.0191	0.0124	6032	15	23	27.9769	6060	15	23	27.9702
70	1	11	40597	9023	15	23	52.0357	8.06411	15	23	43.9716	0.0139	0.0191	0.0124	6032	15	23	43.9768	6060	15	23	43.9701
70	1	11	40597	9023	15	24	8.0356	8.06411	15	23	59.9715	0.0139	0.0191	0.0124	6032	15	23	59.9767	6060	15	23	59.9700
70	1	11	40597	9023	15	24	24.0359	8.06411	15	24	15.9718	0.0139	0.0192	0.0124	6032	15	24	15.9771	6060	15	24	15.9703
70	1	11	40597	9023	18	21	5.5394	8.06446	18	20	57.4749	0.0173	0.0131	0.0209	6032	18	20	57.4707	6060	18	20	57.4785
70	1	11	40597	9023	18	21	21.5389	8.06446	18	21	13.4744	0.0173	0.0131	0.0209	6032	18	21	13.4702	6060	18	21	13.4780
70	1	11	40597	9023	18	21	37.5381	8.06446	18	21	29.4736	0.0172	0.0130	0.0209	6032	18	21	29.4694	6060	18	21	29.4773
70	1	11	40597	9023	18	21	53.5375	8.06446	18	21	45.4730	0.0172	0.0130	0.0209	6032	18	21	45.4688	6060	18	21	45.4767
70	1	11	40597	9023	18	22	9.5362	8.06446	18	22	1.4717	0.0172	0.0130	0.0209	6032	18	22	1.4675	6060	18	22	1.4754
70	1	12	40599	9023	15	23	53.3274	8.06697	15	23	45.2604	0.0136	0.0188	0.0122	6032	15	23	45.2656	6060	15	23	45.2590
70	1	12	40598	9023	15	24	9.3279	8.06697	15	24	1.2609	0.0136	0.0188	0.0122	6032	15	24	1.2661	6060	15	24	1.2595
70	1	12	40598	9023	15	24	25.3283	8.06698	15	24	17.2613	0.0137	0.0188	0.0123	6032	15	24	17.2664	6060	15	24	17.2599
70	1	12	40598	9023	15	24	41.3289	8.06698	15	24	33.2619	0.0137	0.0189	0.0123	6032	15	24	33.2671	6060	15	24	33.2605
70	1	12	40598	9023	15	24	57.3296	8.06698	15	24	49.2626	0.0138	0.0189	0.0123	6032	15	24	49.2677	6060	15	24	49.2611
70	1	13	40599	9023	15	23	53.6554	8.06982	15	23	45.5856	0.0134	0.0184	0.0121	6032	15	23	45.5906	6060	15	23	45.5843
70	1	13	40599	9023	15	24	9.6553	8.06982	15	24	1.5855	0.0134	0.0185	0.0122	6032	15	24	1.5906	6060	15	24	1.5843
70	1	13	40599	9023	15	24	25.6554	8.06982	15	24	17.5856	0.0135	0.0185	0.0122	6032	15	24	17.5906	6060	15	24	17.5843
70	1	13	40599	9023	15	24	41.6554	8.06982	15	24	33.5856	0.0135	0.0186	0.0122	6032	15	24	33.5907	6060	15	24	33.5843
70	1	13	40599	9023	15	24	57.6550	8.06982	15	24	49.5852	0.0136	0.0186	0.0123	6032	15	24	49.5902	6060	15	24	49.5839
70	1	13	40599	9023	15	25	13.6562	8.06982	15	25	5.5864	0.0136	0.0187	0.0123	6032	15	25	5.5915	6060	15	25	5.5851
70	1	19	40605	9023	18	21	39.8374	8.08726	18	21	31.7501	0.0193	0.0138	0.0232	6032	18	21	31.7446	6060	18	21	31.7540
70	1	19	40605	9023	18	21	55.8377	8.08726	18	21	47.7504	0.0193	0.0138	0.0233	6032	18	21	47.7449	6060	18	21	47.7544
70	1	19	40605	9023	18	22	11.8373	8.08726	18	22	3.7500	0.0193	0.0138	0.0233	6032	18	22	3.7445	6060	18	22	3.7540
70	1	19	40605	9023	18	22	27.8371	8.08726	18	22	19.7498	0.0194	0.0138	0.0233	6032	18	22	19.7442	6060	18	22	19.7537
70	1	25	40611	9023	15	16	2.2483	8.10399	15	15	54.1443	0.0127	0.0146	0.0138	6032	15	15	54.1462	6060	15	15	54.1454
70	1	25	40611	9023	15	16	18.2478	8.10399	15	16	10.1438	0.0125	0.0145	0.0137	6032	15	16	10.1458	6060	15	16	10.1450
70	1	25	40611	9023	15	16	34.2471	8.10399	15	16	26.1431	0.0124	0.0144	0.0136	6032	15	16	26.1451	6060	15	16	26.1443
70	1	25	40611	9023	15	16	50.2466	8.10399	15	16	42.1426	0.0123	0.0143	0.0135	6032	15	16	42.1446	6060	15	16	42.1438
70	1	25	40611	9023	15	17	6.2457	8.10399	15	16	58.1417	0.0122	0.0143	0.0133	6032	15	16	58.1438	6060	15	16	58.1428
70	1	26	40612	9023	15	17	11.0311	8.10683	15	17	2.9243	0.0123	0.0141	0.0136	6032	15	17	2.9261	6060	15	17	2.9256
70	1	26	40612	9023	15	17	27.0312	8.10683	15	17	18.9244	0.0122	0.0140	0.0135	6032	15	17	18.9262	6060	15	17	18.9257
70	1	26	40612	9023	15	17	43.0308	8.10683	15	17	34.9240	0.0120	0.0139	0.0134	6032	15	17	34.9259	6060	15	17	34.9254
70	1	26	40612	9023	15	17	59.0308	8.10683	15	17	50.9240	0.0119	0.0139	0.0133	6032	15	17	50.9260	6060	15	17	50.9254
70	1	26	40612	9023	15	18	15.0298	8.10683	15	18	6.9230	0.0118	0.0138	0.0132	6032	15	18	6.9250	6060	15	18	6.9244
70	1	27	40613	9023	15	16	9.0292	8.10967	15	16	0.9195	0.0128	0.0142	0.0143	6032	15	16	0.9209	6060	15	16	0.9210
70	1	27	40613	9023	15	16	25.0293	8.10967	15	16	16.9196	0.0127	0.0141	0.0142	6032	15	16	16.9210	6060	15	16	16.9211
70	1	27	40613	9023	15	16	41.0292	8.10967	15	16	32.9195	0.0126	0.0140	0.0140	6032	15	16	32.9209	6060	15	16	32.9209
70	1	27	40613	9023	15	16	57.0287	8.10967	15	16	48.9190	0.0124	0.0139	0.0139	6032	15	16	48.9205	6060	15	16	48.9205
70	1	27	40613	9023	15	17	13.0284	8.10967	15	17	4.9187	0.0123	0.0138	0.0138	6032	15	17	4.9202	6060	15	17	4.9202

2.2 Adjustment of the World Geometric Satellite Network (WN14)

2.21 Comparison with Other Solutions

Subsequent to the Twelfth Semi-annual Status Report where the details of the OSU WN14 Solution were reported (for a summary see Attachment 2-2 at the end of Section 2), and utilizing the new data available (see sections 2.11 to section 2.13 above), the following transformations between OSU Solution WN14 and other solutions were made:

(a) with NGS (Geometric) (Table 2.2-1)

(b) with NGS (Final Combined) (Table 2.2-2)

(c) with GEM 6 (Table 2.2-3)

(d) with SAO-III (Table 2.2-4)

Based on the above transformations Figures 5.1-2, 5.4-1 and 5.4-2 in the Appendix of the Twelfth Semiannual Status Report (see as Figures 3-5 in Attachment 2-2) were redrawn incorporating the new information mentioned above. The revised figures are given as Figures 2.2-1, 2 and 3, respectively.

2.22 Supplementary Work to NGSP report

Our world net solution WN14 has many areas where the strength of the net can be further improved with inclusion of extra observations.

In this connection, it is proposed to improve the solution WN14 with the incorporation of ISAGEX data vide section 2.14. The preliminary screening, extraction of useful data and reduction of observations so far available has been started.

Similar action in respect of the WEST and EUROAFRIQUE and Baker-Nunn/BC-4 connection data will be taken on its receipt.

For other supplementary work see also section 3.11.

Table 2.2-1

Transformation: NGS (Geom.)-WN14

SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
-1.11	-7.21	11.65	-2.27	0.11	-0.05	-0.08

VARIANCE - COVARIANCE MATRIX

SO2= 1.03

0.844D+00	0.121D-02	-0.203D-02	-0.317D-09	0.328D-08	0.434D-08	0.130D-09
0.121D-02	0.103D+01	0.650D-04	0.429D-08	0.124D-08	-0.161D-09	-0.499D-08
-0.203D-02	0.650D-04	0.127D+01	-0.439D-08	0.183D-10	-0.145D-08	-0.502D-08
-0.317D-09	0.429D-08	-0.439D-08	0.213D-14	-0.521D-17	-0.402D-17	0.477D-17
0.328D-08	0.124D-08	0.183D-10	-0.521D-17	0.211D-14	-0.185D-15	0.550D-16
0.434D-08	-0.161D-09	-0.145D-08	-0.402D-17	-0.185D-15	0.253D-14	0.196D-16
0.130D-09	-0.499D-08	-0.502D-08	0.477D-17	0.550D-16	0.196D-16	0.283D-14

COEFFICIENTS OF CORRELATION

0.100D+01	0.130D-02	-0.196D-02	-0.748D-02	0.777D-01	0.941D-01	0.265D-02
0.130D-02	0.100D+01	0.566D-04	0.915D-01	0.264D-01	-0.314D-02	-0.923D-01
-0.196D-02	0.566D-04	0.100D+01	-0.842D-01	0.353D-03	-0.256D-01	-0.835D-01
-0.748D-02	0.915D-01	-0.842D-01	0.100D+01	-0.245D-02	-0.173D-02	0.194D-02
0.777D-01	0.264D-01	0.353D-03	-0.245D-02	0.100D+01	-0.800D-01	0.224D-01
0.941D-01	-0.314D-02	-0.256D-01	-0.173D-02	-0.800D-01	0.100D+01	0.734D-02
0.265D-02	-0.923D-01	-0.835D-01	0.194D-02	0.224D-01	0.734D-02	0.100D+01

Table 2.2-1 cont.

RESIDUALS V

	V1(WN14)				V2(NGS-GEO)			V1 - V2		
6001	0.4	1.7	1.5	6001	-0.7	-7.4	-4.7	1.1	9.1	6.2
6002	2.2	1.2	-0.5	6002	-0.0	-0.0	0.0	2.2	1.2	-0.5
6003	-3.1	0.1	-0.6	6003	1.0	-0.5	2.1	-4.1	0.6	-2.7
6004	0.7	0.3	0.9	6004	-5.0	-1.7	-5.9	5.7	2.0	6.7
6006	0.3	1.5	1.5	6006	-1.8	-9.1	-9.1	2.1	10.6	10.6
6007	0.8	1.3	0.0	6007	-9.6	-12.2	-0.1	10.4	13.5	0.2
6008	-0.1	-0.0	0.7	6008	1.1	0.2	-6.2	-1.2	-0.2	6.9
6009	-2.7	-0.7	-0.4	6009	8.7	4.8	1.9	-11.4	-5.5	-2.3
6011	-1.8	-0.7	-0.2	6011	11.0	3.5	0.8	-12.8	-4.2	-1.0
6012	0.8	-1.1	-2.7	6012	-11.4	10.5	17.7	12.2	-11.6	-20.4
6013	2.6	-0.8	-1.1	6013	-14.6	4.2	3.9	17.2	-5.0	-5.1
6015	-0.3	-0.3	-0.0	6015	2.7	4.6	0.3	-3.1	-4.9	-0.3
6016	0.5	0.9	0.3	6016	-5.2	-8.8	-3.3	5.7	9.8	3.6
6019	-1.7	-0.7	-3.1	6019	12.2	4.8	24.1	-14.0	-5.5	-27.1
6020	-0.9	-0.9	-1.6	6020	1.7	3.8	6.0	-2.7	-4.7	-7.6
6022	-0.8	-0.7	0.6	6022	4.3	2.8	-2.2	-5.1	-3.5	2.8
6023	0.5	-1.4	0.6	6023	-2.3	11.2	-3.0	2.7	-12.6	3.6
6031	0.1	-1.1	0.6	6031	-0.5	4.4	-3.9	0.6	-5.5	4.5
6032	3.0	-0.7	2.7	6032	-13.0	5.2	-15.2	16.0	-5.9	17.9
6038	-1.6	-1.5	-0.6	6038	2.3	5.7	1.6	-3.9	-7.2	-2.2
6039	-1.5	-0.9	-1.0	6039	3.8	2.9	4.0	-5.4	-3.8	-5.0
6040	2.3	-0.1	0.0	6040	-6.1	0.9	-0.0	8.5	-1.1	0.0
6042	-0.4	-0.4	1.6	6042	5.6	6.3	-11.7	-6.0	-6.7	13.3
6043	-2.4	-2.3	-3.0	6043	8.6	8.6	19.5	-10.9	-10.9	-22.5
6044	0.2	0.1	2.4	6044	-0.4	-0.5	-8.9	0.6	0.6	11.3
6045	-0.6	-0.4	1.3	6045	2.7	3.0	-6.9	-3.4	-3.3	8.2
6047	1.9	-0.8	0.9	6047	-18.3	14.6	-7.4	20.2	-15.4	8.3
6050	-3.7	5.2	-4.2	6050	9.5	-16.5	26.3	-13.2	21.8	-30.5
6051	0.7	-1.3	0.2	6051	-1.8	6.2	-1.2	2.6	-7.5	1.4
6052	2.3	-0.5	-0.2	6052	-6.4	2.5	1.0	8.8	-3.1	-1.2
6053	2.5	-0.7	-0.1	6053	-6.6	2.4	0.4	9.1	-3.1	-0.5
6055	0.6	0.9	-1.1	6055	-6.4	-8.5	9.8	6.9	9.4	-11.0
6059	-0.9	0.1	0.3	6059	7.9	-0.8	-1.3	-8.8	0.9	1.6
6060	0.2	-1.1	0.3	60	-1.1	7.0	-1.5	1.3	-8.1	1.8
6061	-0.6	1.2	-3.3	6061	2.3	-3.1	19.3	-2.9	4.3	-22.6
6063	0.3	0.9	0.2	63	-5.0	-9.0	-1.6	5.3	9.9	1.8
6064	0.3	1.1	0.3	6064	-2.1	-6.4	-1.3	2.4	7.4	1.6

Table 2.2-1 cont.

RESIDUALS V

	V1(WN14)				V2(NGS-GEO)			V1 - V2		
6065	-0.3	0.8	0.3	6065	2.4	-5.9	-2.8	-2.7	6.7	3.1
6067	1.1	-0.1	-1.1	6067	-15.2	0.9	10.9	16.3	-1.0	-12.0
6068	-0.8	-0.7	1.9	6068	5.2	5.0	-10.4	-6.0	-5.7	12.2
6069	1.0	3.8	-2.7	6069	-3.6	-9.6	8.3	4.7	13.5	-11.0
6072	1.5	-2.2	-0.4	6072	-3.3	14.9	1.6	4.8	-17.0	-2.0
6073	-0.4	-0.9	1.4	6073	1.4	6.6	-5.7	-1.8	-7.5	7.1
6075	-0.9	-0.2	1.2	6075	3.3	1.7	-5.5	-4.1	-1.9	6.7
6111	-1.7	-0.9	0.3	6111	2.5	5.2	-1.2	-4.1	-6.1	1.5

Table 2.2-2

Transformation: NGS (Dyn.)-WN14

SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
18.80	9.29	-3.20	-2.28	0.08	-0.06	-0.08

VARIANCE - COVARIANCE MATRIX

SO2= 1.07

0.786D+00	0.798D-04	-0.229D-03	-0.711D-09	-0.101D-09	0.993D-09	-0.122D-10
0.798D-04	0.793D+00	-0.719D-04	-0.241D-09	0.785D-09	-0.379D-10	-0.785D-09
-0.229D-03	-0.719D-04	0.988D+00	-0.685D-09	0.626D-10	-0.966D-09	0.469D-09
-0.711D-09	-0.241D-09	-0.685D-09	0.124D-14	-0.700D-19	0.158D-18	0.154D-17
-0.101D-09	0.785D-09	0.626D-10	-0.700D-19	0.128D-14	-0.702D-16	0.647D-16
0.993D-09	-0.379D-10	-0.966D-09	0.158D-18	-0.702D-16	0.154D-14	-0.132D-16
-0.122D-10	-0.785D-09	0.469D-09	0.154D-17	0.647D-16	-0.132D-16	0.158D-14

COEFFICIENTS OF CORRELATION

0.100D+01	0.101D-03	-0.260D-03	-0.228D-01	-0.318D-02	0.285D-01	-0.345D-03
0.101D-03	0.100D+01	-0.812D-04	-0.768D-02	0.246D-01	-0.108D-02	-0.221D-01
-0.260D-03	-0.812D-04	0.100D+01	-0.196D-01	0.176D-02	-0.247D-01	0.119D-01
-0.228D-01	-0.768D-02	-0.196D-01	0.100D+01	-0.555D-04	0.114D-03	0.110D-02
-0.318D-02	0.246D-01	0.176D-02	-0.555D-04	0.100D+01	-0.499D-01	0.454D-01
0.285D-01	-0.108D-02	-0.247D-01	0.114D-03	-0.499D-01	0.100D+01	-0.845D-02
-0.345D-03	-0.221D-01	0.119D-01	0.110D-02	0.454D-01	-0.845D-02	0.100D+01

Table 2.2-2 cont.

RESIDUALS V

	V1(WN14)				V2(NGS-DYN)			V1 - V2		
6001	0.2	1.8	0.8	6001	-0.4	-4.9	-1.9	0.6	6.7	2.7
6002	0.6	0.1	0.2	6002	-2.3	-0.8	-1.4	2.8	0.9	1.6
6003	-0.5	0.3	-0.2	6003	1.5	-1.2	0.8	-2.0	1.5	-0.9
6004	1.4	-0.2	-0.5	6004	-6.9	0.6	1.5	8.4	-0.8	-1.9
6006	0.0	1.8	1.8	6006	-0.0	-4.1	-5.7	0.1	5.9	7.5
6007	0.9	2.1	0.2	6007	-5.6	-8.8	-0.9	6.5	10.8	1.0
6008	0.2	-0.3	1.5	6008	-1.2	2.2	-6.0	1.4	-2.5	7.5
6009	-1.7	-1.4	-0.6	6009	3.7	5.2	1.2	-5.4	-6.6	-1.8
6011	-3.5	0.2	-0.6	6011	11.4	-0.4	1.4	-14.9	0.6	-2.0
6012	0.6	-0.6	-4.1	6012	-3.8	2.0	11.7	4.3	-2.6	-15.8
6013	4.3	-0.1	-4.3	6013	-10.8	0.3	6.3	15.1	-0.4	-10.6
6015	-1.2	-0.8	-0.7	6015	4.1	3.2	2.0	-5.2	-4.0	-2.7
6016	0.7	1.6	0.4	6016	-3.3	-5.1	-1.6	4.0	6.7	2.0
6019	-2.2	-1.5	-5.3	6019	7.6	4.8	10.9	-9.7	-6.2	-16.2
6020	2.7	-1.4	-2.3	6020	-3.7	3.0	3.0	6.3	-4.4	-5.3
6022	-3.0	0.7	0.4	6022	6.9	-1.1	-0.5	-9.9	1.8	0.9
6023	-0.1	-1.6	0.8	6023	0.1	2.8	-0.9	-0.2	-4.4	1.7
6031	-0.8	0.7	1.4	6031	1.3	-0.8	-2.1	-2.1	1.5	3.5
6032	4.9	-0.3	7.0	6032	-7.8	0.6	-9.4	12.7	-1.0	16.3
6038	-0.4	-1.5	-0.1	6038	1.2	5.0	0.2	-1.6	-6.5	-0.3
6039	-1.3	-0.6	-1.5	6039	3.6	1.7	3.8	-4.9	-2.2	-5.3
6040	2.6	0.6	-1.6	6040	-3.5	-1.0	1.9	6.2	1.6	-3.6
6042	-1.1	-1.1	3.0	6042	5.4	4.8	-6.6	-6.5	-5.9	9.7
6043	-1.9	-4.7	-2.6	6043	3.5	8.8	4.1	-5.4	-13.5	-6.7
6044	-0.4	1.1	2.6	6044	0.9	-3.1	-7.2	-1.3	4.1	9.9
6045	-1.4	-0.4	2.0	6045	2.8	0.9	-2.6	-4.2	-1.3	4.6
6047	3.4	-1.6	1.2	6047	-13.2	7.8	-3.6	16.6	-9.4	4.9
6050	-3.5	5.2	-4.8	6050	4.8	-7.1	7.8	-8.2	12.3	-12.6
6051	0.2	-1.2	0.1	6051	-0.4	2.5	-0.2	0.5	-3.7	0.3
6052	1.7	0.9	-0.7	6052	-3.0	-1.7	1.4	4.7	2.7	-2.1
6053	1.6	1.1	-0.4	6053	-2.3	-1.4	0.9	3.9	2.6	-1.3
6055	0.8	1.0	-2.0	6055	-3.8	-4.2	6.5	4.6	5.2	-8.5
6059	-3.0	1.4	0.5	6059	10.3	-3.4	-0.9	-13.2	4.8	1.4
6060	-0.4	-0.1	0.3	6060	0.7	0.2	-0.4	-1.1	-0.3	0.8
6061	-0.1	-1.0	-2.7	6061	0.4	1.6	6.2	-0.6	-2.7	-8.8
6063	0.4	1.4	0.5	6063	-3.1	-5.0	-1.9	3.5	6.5	2.4
6064	0.4	2.0	0.4	6064	-1.1	-4.2	-0.6	1.5	6.2	1.0

Table 2.2-2 cont.

RESIDUALS V

	V1(WN14)				V2(NGS-DYN)			V1 - V2		
6065	-1.1	0.9	-0.0	6065	4.0	-2.2	0.1	-5.1	3.1	-0.1
6067	1.7	-0.6	-1.6	6067	-11.8	3.7	6.1	13.5	-4.3	-7.7
6068	-1.2	-1.5	3.3	6068	3.6	3.1	-5.5	-4.8	-4.6	8.9
6069	0.6	2.2	-0.3	6069	-2.0	-4.6	0.8	2.5	6.7	-1.1
6072	-0.0	-3.9	-2.3	6072	0.0	7.7	3.1	-0.0	-11.6	-5.4
6073	-0.9	-1.4	1.1	6073	1.8	3.3	-1.6	-2.7	-4.7	2.8
6075	-1.5	0.2	0.9	6075	2.6	-0.4	-1.2	-4.1	0.6	2.1
6111	-0.5	-0.9	0.3	6111	1.4	5.3	-1.6	-1.9	-6.2	2.0

Table 2.2-3

Transformation: GEM 6-WN14

SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
17.55	11.01	4.52	0.68	0.09	0.14	0.11

VARIANCE - COVARIANCE MATRIX

SD2= 1.01

0.779D+00	-0.922D-03	0.302D-03	-0.105D-08	0.321D-08	0.264D-08	0.550D-10
-0.922D-03	0.743D+00	0.162D-02	0.334D-08	0.123D-08	-0.621D-09	-0.296D-08
0.302D-03	0.162D-02	0.778D+00	-0.252D-08	0.562D-09	-0.180D-08	-0.418D-08
-0.105D-08	0.334D-08	-0.252D-08	0.111D-14	-0.228D-18	-0.397D-18	0.155D-17
0.321D-08	0.123D-08	0.562D-09	-0.228D-18	0.139D-14	-0.349D-15	-0.105D-15
0.264D-08	-0.621D-09	-0.180D-08	-0.397D-18	-0.349D-15	0.178D-14	0.173D-15
0.550D-10	-0.296D-08	-0.418D-08	0.155D-17	-0.105D-15	0.173D-15	0.137D-14

COEFFICIENTS OF CORRELATION

0.100D+01	-0.121D-02	0.388D-03	-0.356D-01	0.976D-01	0.707D-01	0.168D-02
-0.121D-02	0.100D+01	0.213D-02	0.116D+00	0.384D-01	-0.171D-01	-0.927D-01
0.388D-03	0.213D-02	0.100D+01	-0.857D-01	0.171D-01	-0.483D-01	-0.128D+00
-0.356D-01	0.116D+00	-0.857D-01	0.100D+01	-0.184D-03	-0.282D-03	0.126D-02
0.976D-01	0.384D-01	0.171D-01	-0.184D-03	0.100D+01	-0.222D+00	-0.759D-01
0.707D-01	-0.171D-01	-0.483D-01	-0.282D-03	-0.222D+00	0.100D+01	0.111D+00
0.168D-02	-0.927D-01	-0.128D+00	0.126D-02	-0.759D-01	0.111D+00	0.100D+01

Table 2.2-3 cont.

RESIDUALS V

	V1(WN14)				V2(GEM-6)			V1 - V2		
1021	0.3	-0.0	4.5	1021	-0.5	0.0	-7.6	0.7	-0.0	12.1
1022	0.5	0.7	0.0	1022	-1.4	-2.4	-0.0	2.0	3.0	0.0
1030	-7.0	0.7	1.3	1030	3.0	-0.9	-1.7	-10.0	1.6	3.0
1032	49.7	70.8	11.0	1032	-3.1	-3.1	-5.6	52.7	73.9	16.5
1034	-4.1	2.4	1.5	1034	5.8	-3.8	-2.8	-10.0	6.2	4.3
1042	3.7	-0.2	-0.5	1042	-6.5	0.4	0.8	10.2	-0.5	-1.2
4050	-0.8	0.3	-0.2	4050	16.6	-6.9	1.8	-17.3	7.2	-2.0
4082	0.6	-0.7	-0.2	4082	-3.4	5.0	1.0	4.0	-5.8	-1.2
4740	-1.6	-1.8	3.9	4740	3.4	4.5	-6.5	-4.9	-6.3	10.4
6002	-0.4	-0.9	0.5	6002	1.4	4.0	-1.7	-1.8	-4.9	2.2
6003	0.3	-0.2	-0.3	6003	-7.9	7.1	8.0	8.2	-7.4	-8.3
6004	0.1	-0.2	-0.0	6004	-12.5	13.9	1.1	12.6	-14.1	-1.1
6006	0.1	0.4	-0.6	6006	-5.4	-17.7	22.4	5.5	18.1	-23.0
6007	0.2	0.5	-0.2	6007	-7.9	-18.9	6.7	8.1	19.4	-6.9
6008	0.0	0.0	0.1	6008	-0.6	-0.9	-4.1	0.6	0.9	4.2
6009	0.1	-0.1	-0.2	6009	-2.6	3.3	6.1	2.6	-3.4	-6.3
6011	1.0	0.1	-0.2	6011	-2.6	-0.3	0.4	3.7	0.4	-0.5
6012	0.5	-0.3	-0.4	6012	-24.3	10.0	9.2	24.8	-10.3	-9.6
6013	0.4	-0.7	-0.3	6013	-15.5	14.5	6.0	15.9	-15.1	-6.3
6015	-0.0	-0.7	-0.9	6015	0.8	17.1	15.5	-0.9	-17.8	-16.4
6016	0.2	0.5	-0.5	6016	-5.9	-13.4	12.9	6.1	13.9	-13.5
6019	0.1	-1.2	-9.5	6019	-0.3	3.9	17.0	0.4	-5.1	-26.5
6020	0.2	0.2	-0.3	6020	-5.8	-8.4	6.0	6.0	8.6	-6.3
6022	0.2	0.2	0.6	6022	-2.8	-2.8	-5.0	2.9	3.0	5.6
6023	0.5	-0.4	-0.3	6023	-6.9	7.3	3.2	7.4	-7.7	-3.5
6031	0.3	0.5	0.2	6031	-2.7	-4.2	-2.1	3.0	4.8	2.3
6032	1.9	-0.5	2.7	6032	-13.1	3.6	-12.8	15.1	-4.1	15.5
6038	0.0	-0.1	-0.1	6038	-0.9	2.9	0.5	1.0	-3.0	-0.6
6039	0.0	0.3	-0.1	6039	-1.1	-10.1	3.2	1.1	10.4	-3.3
6040	2.4	-0.7	-0.0	6040	-21.3	9.0	0.3	23.7	-9.6	-0.4
6042	-0.5	-1.2	0.0	6042	4.7	10.7	-0.2	-5.2	-11.9	0.2
6043	-0.3	-0.1	-1.1	6043	5.8	1.0	8.7	-6.1	-1.1	-9.8
6044	0.9	-0.6	-0.3	6044	-7.8	6.1	1.7	8.7	-6.8	-1.9
6045	0.3	-0.3	0.4	6045	-5.8	5.6	-4.2	6.1	-5.9	4.6
6047	0.3	-0.3	-0.2	6047	-17.9	18.4	5.5	18.3	-18.8	-5.7
6050	-0.4	0.6	-2.0	6050	5.3	-5.7	18.2	-5.7	6.3	-20.2
6051	1.4	0.4	0.5	6051	-10.4	-5.2	-5.1	11.8	5.6	5.6

Table 2.2-3 cont.

RESIDUALS V

	V1(WN14)				V2(GEM-6)			V1 - V2		
6052	0.3	0.3	0.7	6052	-2.9	-3.7	-4.0	3.2	4.0	4.7
6053	0.6	0.1	0.2	6053	-4.1	-0.8	-1.5	4.7	0.9	1.6
6055	-0.0	0.8	-1.0	6055	0.3	-16.7	15.7	-0.3	17.5	-16.7
6060	0.2	-0.2	-0.1	6060	-1.4	1.1	0.5	1.6	-1.3	-0.6
6061	0.5	1.7	-0.5	6061	-7.7	-11.2	3.6	8.2	12.9	-4.1
6063	0.1	0.6	-0.5	6063	-4.0	-18.0	11.0	4.1	18.6	-11.5
6064	-0.3	0.7	-1.1	6064	3.4	-7.3	7.9	-3.8	8.0	-9.1
6067	-0.0	0.2	-0.8	6067	0.9	-7.4	17.2	-0.9	7.6	-18.0
6068	0.0	1.0	0.6	6068	-0.0	-1.6	-0.5	0.0	2.7	1.1
6069	-0.3	1.3	0.4	6069	3.4	-17.6	-3.2	-3.6	19.0	3.6
6072	2.0	-1.1	-0.5	6072	-17.9	20.4	7.3	19.9	-21.5	-7.8
6073	0.6	-0.6	0.2	6073	-11.2	9.5	-2.6	11.9	-10.1	2.8
6111	0.1	-0.7	-0.3	6111	-1.2	8.1	2.9	1.4	-8.8	-3.2
6123	0.6	-0.5	-0.7	6123	-29.7	28.4	35.7	30.3	-29.0	-36.4
7036	-5.1	2.9	-0.9	7036	5.7	-6.5	1.4	-10.8	9.4	-2.3
7037	-1.5	2.0	1.1	7037	2.5	-5.8	-2.6	-4.0	7.8	3.7
7039	-1.6	-1.8	3.7	7039	3.5	4.5	-6.7	-5.1	-6.3	10.3
7040	-1.2	2.4	0.8	7040	1.1	-3.2	-0.7	-2.3	5.6	1.5
7043	-0.4	-0.9	0.5	7043	1.4	4.1	-1.8	-1.9	-5.0	2.3
7045	-7.2	2.4	-1.9	7045	5.7	-4.2	3.0	-12.9	6.6	-4.9
7072	1.5	-0.9	-0.2	7072	-4.5	3.8	0.6	6.0	-4.8	-0.8
7075	-2.4	-0.5	0.8	7075	6.3	1.2	-2.5	-8.7	-1.7	3.3
7076	-2.2	-3.9	-2.5	7076	4.9	7.4	3.3	-7.1	-11.3	-5.9
9001	-0.8	0.8	1.7	9001	1.1	-2.4	-5.6	-1.9	3.1	7.3
9002	-0.3	1.1	0.5	9002	0.4	-1.7	-0.3	-0.6	2.7	0.8
9004	-2.5	34.3	-4.1	9004	2.9	-4.7	3.5	-5.5	38.9	-7.6
9005	10.2	-12.5	8.8	9005	-6.5	8.3	-8.4	16.8	-20.8	17.3
9006	8.5	-6.9	1.5	9006	-2.1	8.7	-1.6	10.6	-15.6	3.0
9008	-6.4	4.2	3.8	9008	3.3	-2.7	-2.5	-9.7	6.9	6.3
9009	1.8	-0.6	-0.0	9009	-11.4	5.0	0.0	13.2	-5.5	-0.0
9010	1.5	-0.9	-0.1	9010	-4.4	3.9	0.1	5.9	-4.8	-0.2
9012	0.9	0.1	-0.1	9012	-2.4	-0.3	0.3	3.3	0.5	-0.4
9021	3.0	-0.8	-0.8	9021	-4.3	2.0	2.2	7.3	-2.8	-3.0
9028	1.2	0.2	0.7	9028	-10.4	-1.6	-3.0	11.5	1.8	3.7
9031	-6.2	1.6	-19.0	9031	4.9	-1.1	8.2	-11.1	2.7	-27.2
9091	-5.3	20.9	-2.6	9091	11.5	-7.4	5.1	-16.8	28.3	-7.7
9425	0.1	-0.7	-0.3	9425	-0.9	7.9	3.0	1.0	-8.6	-3.4
9427	2.4	-35.7	5.0	9427	-2.9	8.7	-6.5	5.3	-44.4	11.5

Table 2.2-4

Transformation: SAO III-WN14

SCALE FACTOR AND ROTATION PARAMETERS CONSTRAINED

SOLUTION FOR 3 TRANSLATION, 1 SCALE AND 3 ROTATION PARAMETERS

(USING VARIANCES ONLY)

DU METERS	DV METERS	DW METERS	DELTA (X1.D+6)	OMEGA SECONDS	PSI SECONDS	EPSILON SECONDS
15.42	15.56	-11.24	0.72	0.33	0.05	-0.04

VARIANCE - COVARIANCE MATRIX

SO2= 0.94

0.155D+01	0.710D-03	-0.717D-03	-0.185D-08	0.499D-08	0.337D-08	0.693D-10
0.710D-03	0.159D+01	0.251D-02	0.315D-08	0.263D-08	-0.532D-09	-0.356D-08
-0.717D-03	0.251D-02	0.160D+01	-0.233D-08	0.493D-09	-0.367D-08	-0.599D-08
-0.185D-08	0.315D-08	-0.233D-08	0.160D-14	-0.855D-18	-0.826D-18	0.184D-17
0.499D-08	0.263D-08	0.493D-09	-0.855D-18	0.276D-14	-0.194D-15	-0.164D-15
0.337D-08	-0.532D-09	-0.367D-08	-0.826D-18	-0.194D-15	0.315D-14	0.322D-15
0.693D-10	-0.356D-08	-0.599D-08	0.184D-17	-0.164D-15	0.322D-15	0.308D-14

COEFFICIENTS OF CORRELATION

0.100D+01	0.453D-03	-0.455D-03	-0.372D-01	0.764D-01	0.482D-01	0.100D-02
0.453D-03	0.100D+01	0.157D-02	0.624D-01	0.397D-01	-0.751D-02	-0.509D-01
-0.455D-03	0.157D-02	0.100D+01	-0.460D-01	0.740D-02	-0.516D-01	-0.853D-01
-0.372D-01	0.624D-01	-0.460D-01	0.100D+01	-0.407D-03	-0.368D-03	0.830D-03
0.764D-01	0.397D-01	0.740D-02	-0.407D-03	0.100D+01	-0.656D-01	-0.563D-01
0.482D-01	-0.751D-02	-0.516D-01	-0.368D-03	-0.656D-01	0.100D+01	0.103D+00
0.100D-02	-0.509D-01	-0.853D-01	0.830D-03	-0.563D-01	0.103D+00	0.100D+01

Table 2.2-4 cont.

RESIDUALS V

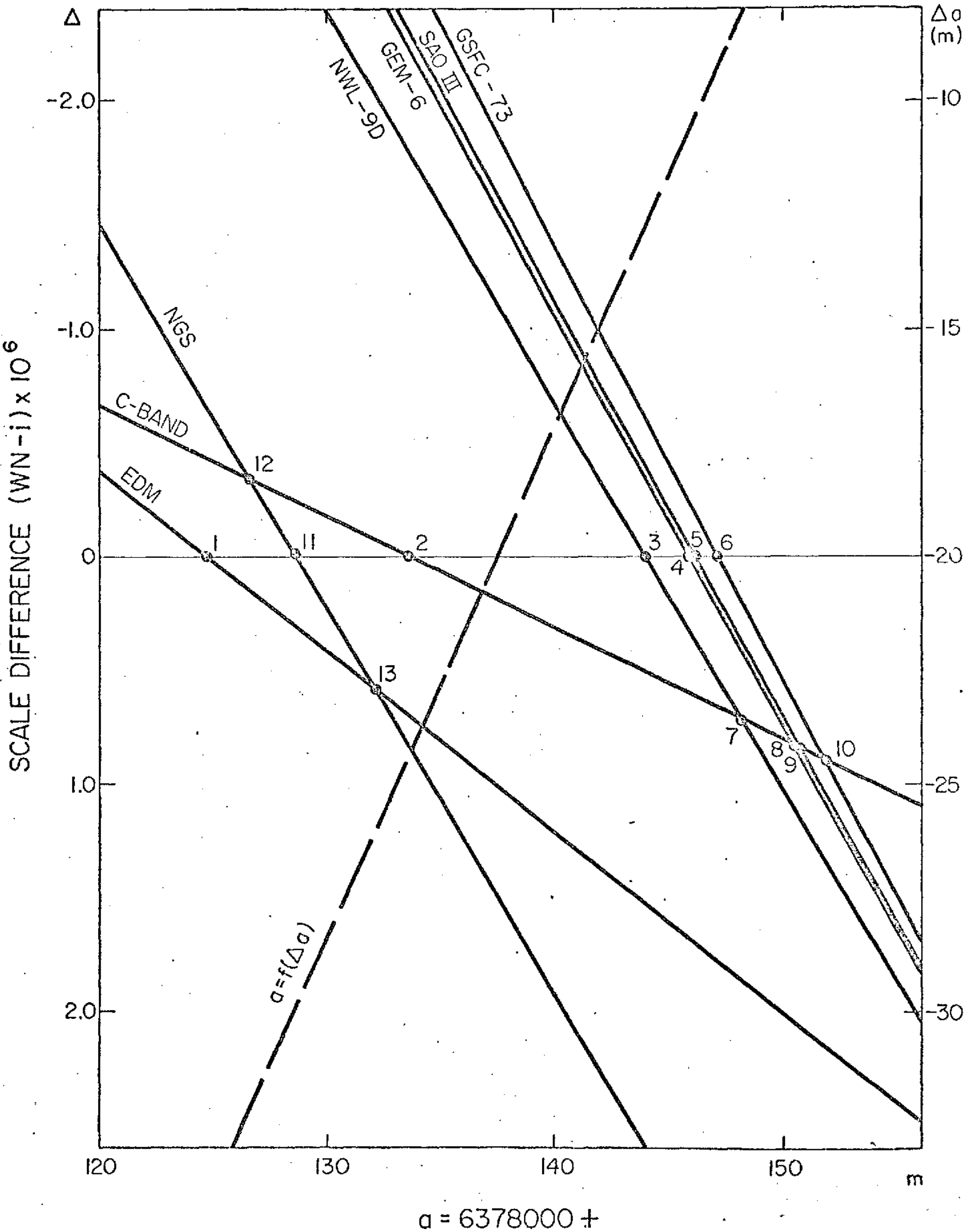
	V1(WN14)				V2(SAO-III)			V1 - V2		
1021	0.3	-1.9	5.5	1021	-0.5	4.9	-12.0	0.8	-6.9	17.5
6001	0.1	0.1	0.1	6001	-5.4	-7.3	-2.4	5.5	7.4	2.4
6002	-0.3	-1.1	0.5	6002	2.5	11.7	-4.0	-2.8	-12.8	4.5
6003	0.0	-0.0	-0.0	6003	-0.1	0.9	0.3	0.1	-0.9	-0.3
6004	0.1	-0.0	0.0	6004	-14.3	1.7	-2.7	14.4	-1.8	2.8
6006	0.0	-0.0	0.0	6006	-1.7	2.1	-1.8	1.7	-2.2	1.8
6007	0.0	0.1	-0.1	6007	-1.7	-6.2	5.9	1.8	6.3	-5.9
6008	0.0	-0.0	-0.1	6008	-3.0	1.8	4.7	3.0	-1.8	-4.7
6009	0.1	0.1	-0.3	6009	-4.7	-5.0	13.5	4.8	5.1	-13.8
6011	0.2	1.5	0.4	6011	-0.8	-8.6	-1.9	1.0	10.1	2.3
6012	0.2	-0.1	-0.3	6012	-30.4	6.3	18.8	30.6	-6.4	-19.1
6013	1.0	-0.7	0.2	6013	-25.1	9.4	-1.9	26.1	-10.1	2.1
6015	-0.0	-0.2	0.1	6015	2.5	15.9	-4.7	-2.5	-16.1	4.8
6016	0.0	-0.0	0.1	6016	-1.3	1.6	-6.1	1.3	-1.6	6.1
6019	0.5	-0.1	-4.7	6019	-4.8	0.8	19.0	5.3	-1.0	-23.7
6020	0.2	0.2	-0.2	6020	-8.6	-14.9	7.5	8.8	15.2	-7.7
6022	0.2	0.4	0.1	6022	-9.0	-15.1	-1.4	9.3	15.5	1.5
6023	0.7	-0.3	0.1	6023	-16.8	8.4	-1.7	17.5	-8.7	1.8
6031	0.4	0.3	0.0	6031	-11.0	-6.4	-0.4	11.5	6.8	0.4
6032	0.8	-0.1	0.9	6032	-26.8	3.2	-21.2	27.6	-3.3	22.1
6038	-0.0	0.0	-0.2	6038	0.7	-0.4	4.1	-0.7	0.4	-4.3
6039	0.2	0.4	-0.1	6039	-8.3	-20.1	5.4	8.5	20.5	-5.5
6040	0.6	-0.2	0.1	6040	-17.3	6.6	-3.2	17.9	-6.7	3.3
6042	-0.4	-0.7	1.3	6042	9.6	16.2	-16.3	-10.0	-16.9	17.6
6043	0.1	0.1	-1.0	6043	-5.2	-4.6	23.6	5.3	4.7	-24.6
6044	0.1	0.5	0.3	6044	-4.8	-23.5	-7.7	4.9	24.0	8.0
6045	-0.1	-0.2	0.5	6045	2.8	7.1	-9.2	-2.9	-7.3	9.7
6047	0.3	-0.1	0.2	6047	-32.5	12.7	-8.8	32.8	-12.8	9.0
6050	0.1	0.6	-0.7	6050	-4.4	-18.4	23.0	4.5	18.9	-23.7
6051	0.2	0.1	-0.0	6051	-4.8	-3.7	0.9	5.0	3.8	-0.9
6052	0.6	0.2	0.0	6052	-17.7	-8.8	-0.3	18.3	9.0	0.3
6053	0.6	0.4	-0.1	6053	-15.5	-10.3	4.3	16.0	10.6	-4.4
6055	-0.0	0.1	-0.1	6055	2.7	-7.4	7.6	-2.7	7.5	-7.7
6059	0.1	0.4	-0.0	6059	-3.2	-16.8	0.2	3.3	17.2	-0.2
6060	2.2	0.1	-0.1	6060	-11.2	-0.7	0.5	13.4	0.9	-0.6
6061	0.2	0.4	-0.6	6061	-9.2	-10.3	16.5	9.3	10.7	-17.1
6063	-0.0	0.0	-0.0	6063	1.6	-4.3	0.9	-1.6	4.4	-0.9

Table 2.2-4 cont.

RESIDUALS V

	V1(WN14)				V2(SAO-III)			V1 - V2		
6064	-0.0	-0.0	0.1	6064	1.3	1.6	-3.2	-1.4	-1.7	3.3
6065	-0.0	-0.0	-0.1	6065	1.3	2.9	10.7	-1.3	-2.9	-10.8
6067	0.4	0.3	-0.6	6067	-7.2	-4.7	6.5	7.6	5.0	-7.1
6068	-1.4	-1.0	-1.6	6068	4.8	3.5	2.8	-6.3	-4.5	-4.4
6069	0.1	0.2	0.0	6069	-3.1	-9.2	-1.2	3.1	9.3	1.3
6072	0.6	-0.4	0.2	6072	-11.1	17.1	-5.8	11.7	-17.5	5.9
6073	0.0	-0.4	0.4	6073	-0.5	13.9	-10.4	0.5	-14.3	10.8
6075	-0.2	-0.4	0.4	6075	4.5	11.5	-11.2	-4.7	-11.9	11.6
6078	-0.6	0.3	3.8	6078	10.8	-8.4	-42.5	-11.4	8.7	46.3
6111	-0.1	0.0	0.2	6111	1.1	-0.4	-1.5	-1.3	0.4	1.6
6123	0.1	-0.0	0.1	6123	-5.3	1.7	-5.0	5.4	-1.8	5.1
6134	-0.1	0.0	0.1	6134	1.2	-0.3	-1.4	-1.3	0.3	1.6
8015	-6.2	22.4	-3.6	8015	7.2	-7.2	3.8	-13.4	29.5	-7.5
8019	-0.9	14.3	-0.2	8019	5.1	-20.9	0.8	-6.0	35.2	-0.9
9001	-8.7	2.6	2.3	9001	13.3	-8.8	-8.5	-21.9	11.4	10.9
9002	-2.3	-1.6	-2.6	9002	4.3	3.1	2.5	-6.5	-4.7	-5.2
9004	-2.1	24.6	-2.4	9004	6.1	-8.5	5.2	-8.2	33.1	-7.6
9005	7.3	-4.7	4.7	9005	-15.4	10.4	-14.9	22.7	-15.1	19.6
9006	12.4	-9.6	3.2	9006	-3.1	12.3	-3.5	15.5	-21.9	6.7
9007	1.6	-2.4	-8.0	9007	-5.0	5.7	8.4	6.6	-8.1	-16.4
9008	-1.8	-2.7	1.1	9008	3.8	7.1	-2.9	-5.5	-9.8	4.1
9009	0.4	-0.2	0.3	9009	-4.2	3.0	-1.5	4.6	-3.2	1.8
9010	0.6	0.0	1.3	9010	-4.6	-0.2	-8.5	5.3	0.2	9.8
9011	0.7	-0.1	-5.8	9011	-5.1	0.7	18.0	5.8	-0.8	-23.8
9012	0.2	2.0	0.5	9012	-0.7	-8.4	-1.8	0.9	10.4	2.3
9021	6.1	-2.8	-3.8	9021	-5.8	4.8	6.5	11.9	-7.7	-10.3
9028	0.3	-0.2	1.7	9028	-6.1	3.5	-19.5	6.4	-3.7	21.1
9029	0.5	0.3	-0.6	9029	-7.2	-4.8	6.2	7.7	5.2	-6.8
9031	-0.7	3.1	-8.7	9031	1.3	-5.2	8.8	-2.0	8.3	-17.4
9091	-2.9	23.3	-1.6	9091	10.6	-13.9	5.3	-13.6	37.2	-6.9
9424	-1.7	1.1	0.6	9114	18.5	-8.9	-8.5	-20.2	10.0	9.2
9425	-0.2	-0.0	0.3	9113	1.4	0.1	-2.3	-1.6	-0.1	2.6
9426	0.2	4.5	-1.3	9115	-0.8	-19.5	15.2	1.0	24.1	-16.5
9427	4.5	-22.0	4.2	9117	-10.0	9.8	-9.8	14.5	-31.7	14.0
9431	-10.1	7.5	-1.0	9074	22.2	-28.5	6.6	-32.4	36.1	-7.6

Fig. 2.2-1
Determination of Scale



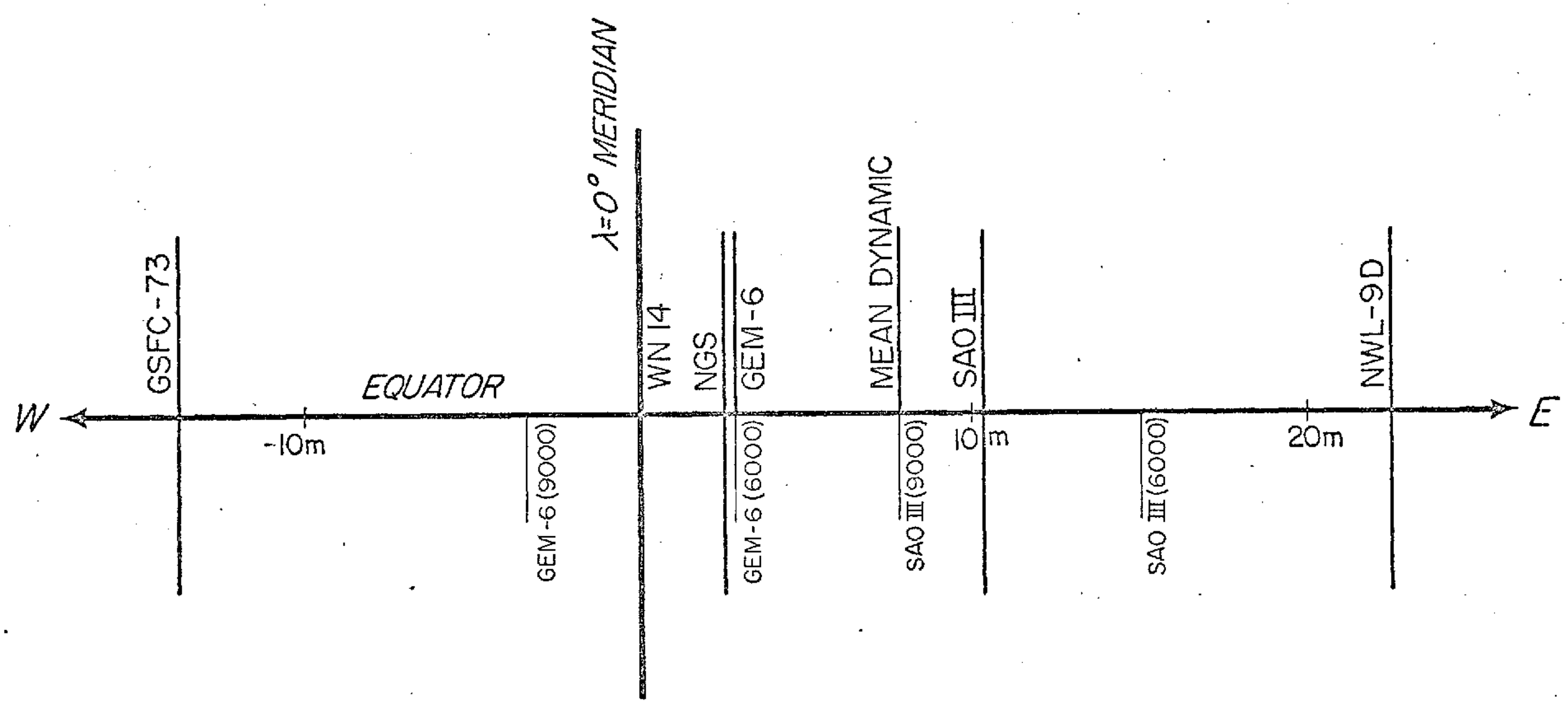


Figure 2.2-2

Zero Meridians of Various Solutions Relative to that of the WN14 Solution.

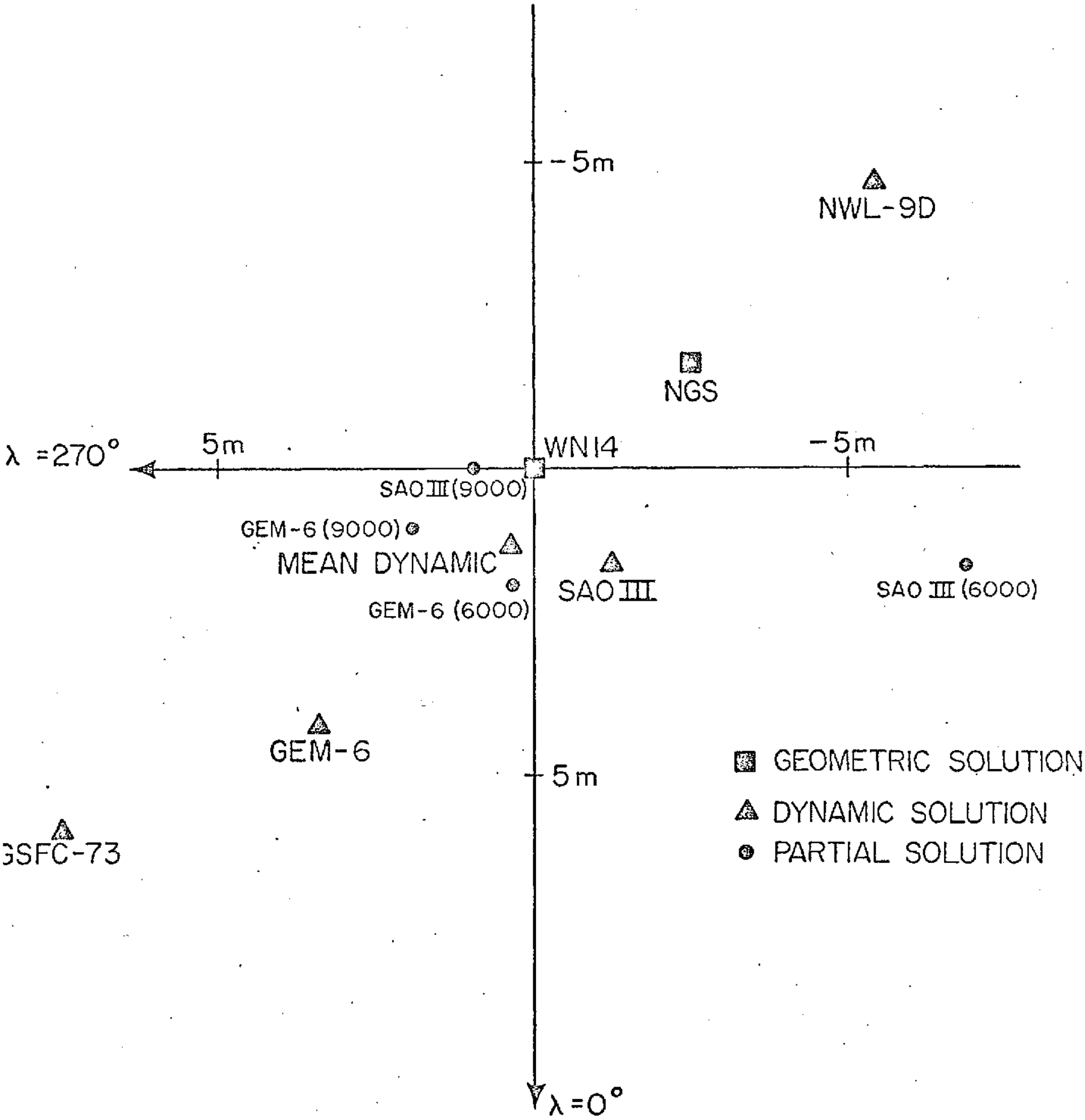


Fig. 2.2-3

North Pole Positions of Various Solutions Relative to that of WN14 Solution

...TE DE RECHERCHES DE GEODESIE SPATIALE

Bureau des Longitudes
Centre National d'Etudes Spatiales
Observatoire de Paris
Institut Géographique National

Directeur exécutif : J. Kovalevsky
Observatoire de Meudon
2 - Meudon (tél. 626-16-30)

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RGS Brétigny : Centre National
Etudes Spatiales - BP n° 4
- Brétigny-sur-Orge
él. 490-92-20, poste 2797)

MLC

Attachment 2-1

Brétigny, le 4 Septembre 1973.-

Dr. I.I. MUELLER
Department of Geodetic Science
OHIO STATE UNIVERSITY
1958 Neil Avenue
COLUMBUS - OHIO 43210 USA

éf. à rappeler
XXXXXX.....
XXXXXX.....
RGS BY/.GB/GR/3.149 -

Ref : Your April 27 and August 7 letters-

Dear Dr. MUELLER,

Please find enclosed a tape and a print-out of all ISAGEX data which are part of a simultaneous event.

This tape includes all observations of every pass during which there is a simobs, according to the simobs catalogue in the ISAGEX / 17 document.

Data are given in the formats described in the ISAGEX / 16 document (ISAGEX Data handling Booklet - April 1973).

The tape includes two files with an end of file in between (EOF). The first file contains the laser data, the second file the optical data. The tape is unlabelled, 7 tracks 556 BPI, BCD Code (even parity) and has been made on a CDC 6600 computer (SCOPE 3.4. system).

These data are not validated. However, some timing errors had been found on the SAO GEOS 2 flash observations. SAO has recently provided corrected data. They are enclosed on punched cards and corresponding print-out. They are to replace the data on the tape.

Updated catalogue of simultaneous observations will be distributed in the future. Please let me know if you want to receive new data.

Best regards,

G. Brachet

Gérard BRACHET
ISAGEX, Project Manager

EARTH PARAMETERS FROM GLOBAL SATELLITE TRIANGULATION AND TRILATERATION

by

Ivan I. Mueller
Department of Geodetic Science
The Ohio State University, Columbus

Presented at the International Symposium on Earth's Gravitational Field and Secular Variations in Position
Sydney, Australia, November 26-30, 1973

Abstract

Results obtained from a 159-station global satellite triangulation and trilateration (including Baker-Nunn, BC-4, PC-1000 camera observations, SECOR, C-Band radar and EDM distance measurements) indicate differences in the semidiameter and orientation of the Earth compared to results obtained from dynamic satellite solutions. Geoidal undulations obtained can be made consistent with dynamically determined ones at the expense of slight changes in the currently accepted parameters defining the gravity field of the level ellipsoid.

1. INTRODUCTION

The global triangulation and trilateration forming the basis of this paper was performed as part of the U.S. National Geodetic Satellite Program. A summary of the networks involved in the adjustments reported here (solutions WN) is presented in Table 1. The data for the MPS and BC networks was obtained through the National Space Science Data Center. The Defense Mapping Agency provided observations for the SECOR and the SA networks (Topographic Center and Aerospace Center respectively). The sources for the constraint information are listed in Table 2. Fig. 1 shows the combined network (WN). Different symbols indicate the various instruments utilized in the observations. Concentric symbols show collocated stations or nearby stations with relative positions known from geodetic surveys. The straight lines between some of the stations illustrate the locations of the baselines.

2. REFERENCE ELLIPSOID, ORIGIN AND ORIENTATION

The least squares adjustment of the observations was performed in terms of the Cartesian coordinates of the tracking stations. The results are also converted into geodetic coordinates (latitude, longitude, height) referenced to a rotational ellipsoid of the following parameters:

$$a = 6\ 378\ 155.00 \text{ m}$$

$$b = 6\ 356\ 769.70 \text{ m}$$

The corresponding flattening is

$$f = 1/298.2494985 = 0.003352897507$$

Table 1

Basic Information on the OSU Solutions (Networks)

OSU Solution (Network)	No. of Stations	No. of Observations	No. of Constraints Used						[6]σ_0	[7]Reference
			Origin	Relative Position	Scale (Length)	Station Position	Height	Directional		
[1]MPS	66	28774	inner	9	7	--	63	--	1.07	188
[2]BC	49	30302	inner	2	7	--	48	--	2.80	193
[3]SECOR	50	28844	inner	14	--	--	37	9	1.37	195
[4]SA	14	2524	inner	3	1	--	14	--	2.50	196
[5]WN	159	90444	inner	43	11	--	158	--	1.02	199

[1]MPS includes 14 PC-1000 stations, 15 MOTS-40 stations, 1 PTH-100 station, 7 C-Band stations, 6 European stations (8000 series), and 23 SAO stations (9000 series).

[2]BC includes all 49 stations of BC-4 Worldwide Geometric Satellite Network.

[3]SECOR includes 37 SECOR stations of the Equatorial Network and 13 collocated BC-4 camera stations.

[4]SA includes 9 PC-1000 stations of South American Densification Net and 5 BC-4 stations.

[5]WN includes all the above-mentioned four networks, namely, MPS (less one C-Band station: 4742), BC, SECOR, and SA.

[6]A posteriori standard deviation of unit weight.

[7]OSU Department of Geodetic Science Report No.

Table 2

Summary of Constraint Types with the Source Information

Code	Constraint Type	Source (Agency)*
	Relative Position	
1	BC-4 - Baker-Nunn	SAO, NGS
2	BC-4 - SECOR	DMA/TC
3	BC-4 - BC-4	NGS
4	Others	OSU
	Height	
5	MSL (mean sea level heights)	CSC, NGS, NWL
6	Geoidal undulations	OSU [Rapp, 1973]
	Length (Chord)	
7	North America	NGS
8	Europe	NGS, DGFI
9	Africa	NGS
10	Australia	NGS, DNP
11	C-Band	NASA/Wallops Isl.

*CSC Computer Sciences Corporation
DGFI Deutsche Geodätisches Forschungsinstitut
DMA/TC Defense Mapping Agency Topographic Center
DNP Division of National Mapping, Dept. of National Development, Australia
NGS National Geodetic Survey
NWL Naval Weapons Laboratory
SAO Smithsonian Astrophysical Observatory

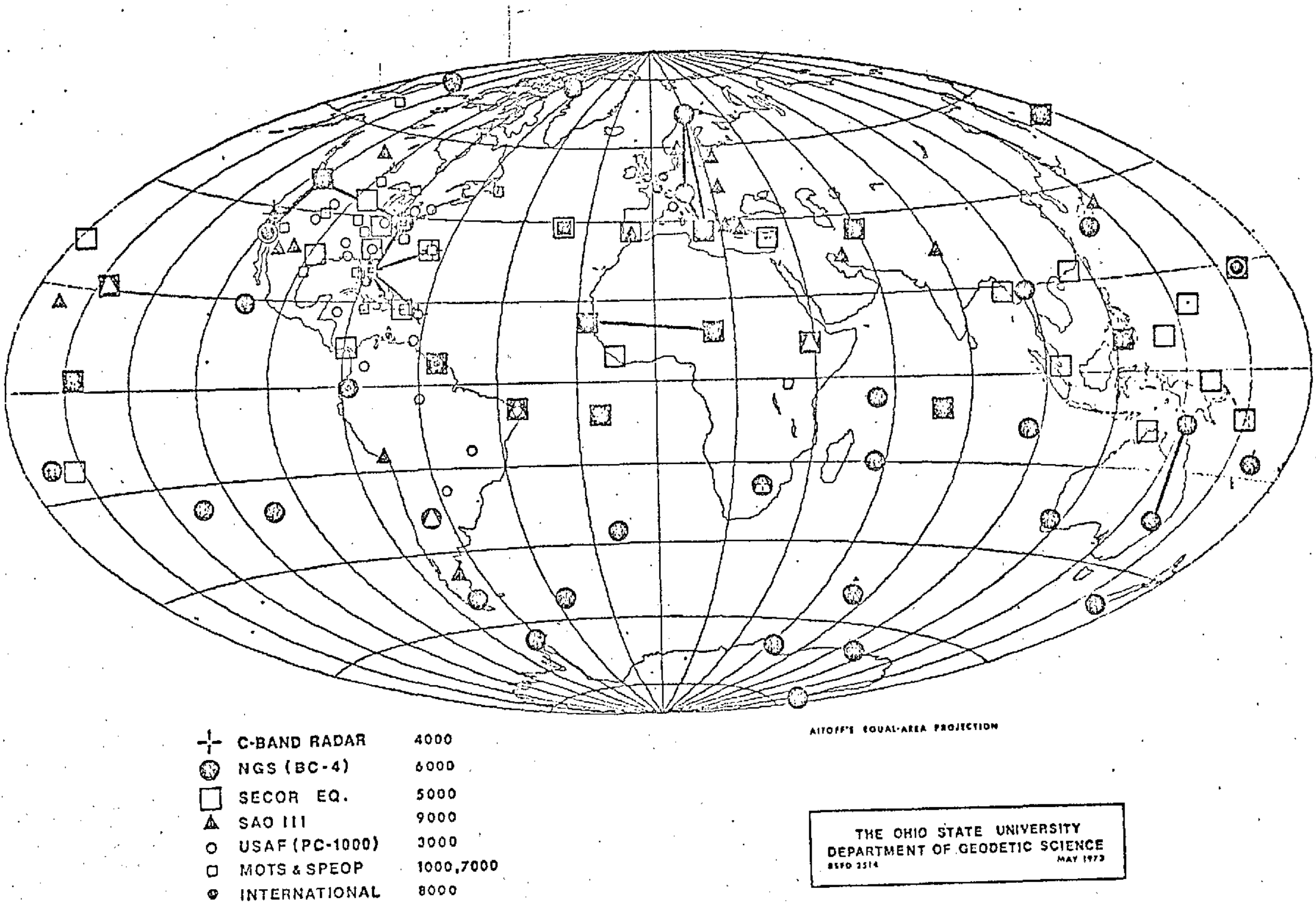

Fig. 1 OSU Geometric Satellite Network (WN)

The origin of the coordinate system (or the center of the above reference ellipsoid) is free as determined through the "inner" constraints explained in [Blaha, 1971]. The orientation of the system is inherent in the optical observations, through the star positions in the SAO catalog (referenced to the FK4 system) updated to their apparent positions at the epoch of the observation, and through UT1, x and y (coordinates of the true pole with respect to the CIO) as derived by the BIH. Thus the positive end of the axis u is in the direction of the Greenwich Mean Astronomical Meridian (and the zero geodetic meridian of the reference ellipsoid); the positive w axis passes through the Conventional International Origin (and coincides with the minor axis of the reference ellipsoid). The axis v completes the right-handed coordinate system in the direction of the 90° (E) meridian, and with the u axis defines the plane of the average terrestrial (geodetic) equator.

3. SCALE

The scale in the solution is defined through the dominating nearly 30,000 SECOR range observations, through the lengths of eight EDM (Geodimeter or Tellurometer) and three C-Band baselines, and also through a special procedure using constrained ellipsoidal heights.

3.1 SECOR Observations

The SECOR observations have an a posteriori standard deviation of ±4.1 m or approximately one part per million [Mueller et al., 1973b]. The scale is propagated into the network through fifteen optical stations whose relative positions with respect to the nearby SECOR stations are maintained in the adjustment with their survey coordinate-differences entered as weighted constraints.

3.2 Baselines

The available EDM and C-Band baselines are listed in Table 3. The chord distances shown are entered in the adjustment as weighted constraints with weights computed from their estimated a priori standard deviations as listed in the table. The reasons for rejecting the east-west Australian tellurometer line (6032-6060) are explained below. Three C-Band lines were also rejected because of suspected errors in the survey coordinates of the terminal stations (Kauai (4742) in Hawaii and Pretoria (4040) in South Africa) needed to tie them to the nearest optical stations (9012 and 9002 respectively). Though these four lines were not constrained, at the end of

Table 3

Chord Constraints

Station-Station	Chord Distance (meters)	$\sigma \times 10^6$ [1]	Source Code[2]
6002-6003	3 485 363.232	1.00	7
6003-6111	1 425 876.452	1.11	7
6006-6065	2 457 765.810	1.43	8
6016-6065	1 194 793.601	1.18	8
6063-6064	3 485 550.755	1.18	9
6023-6060	2 300 209.803	2.00	10
6032-6060 *	3 163 623.866	2.00	10
6006-6016	3 545 871.454	1.00	8
3861-7043	1 531 562.9	1.33	7
4082-4050 *	10 909 .592	1.33	11
4082-4742 *	7 362 142	2.00	11
4082-4740	1 593 106	2.00	11
4082-4081	1 230 691	2.00	11
4082-4061	2 288 026	2.00	11
4742-4280 *	3 977 684	2.00	11

[1] Used in computing the weights.
[2] Refer to Table 2.
* Rejected from the solution.

the analysis two of them (6032-6060 and 4082-4050) compared well with the lengths computed from the adjusted coordinates (see Table 8). Thus the only station with survey coordinates in definite error is Kauai.

To get a feeling for the quality of the EDM baselines listed in Table 3, four preliminary adjustments of the BC network were performed in which the four longest scalars were individually constrained to their measured lengths and their effect on the other (unconstrained) baselines investigated. The results are shown in Table 4 in the form of the differences "adjusted-measured" lengths (Δd). Only independent lines longer than 2000 km are shown since the adjusted length of a short line, due to the geometry resulting from the high altitude of PAGEOS, the satellite used in the BC net, is not reliable. From the table it is clear that holding the east-west Australian line (3032-6060) to its measured value results in unreasonable larger differences of generally opposite signs than in any other case.

Table 4

Adjusted - Given Lengths (m)

Solution	BC-8	BC-9	BC-10	BC-11
Line Fixed	6002-6003	6063-6064	6032-6060	6006-6016
6002-6003	-0.0	- 8.6	33.8	12.4
6006-6016	-13.3	-20.9	22.1	0.0
6063-6064	6.1	0.0	40.5	19.1
6023-6060	- 9.5	-14.6	12.4	- 0.7
6032-6060	-29.5	-36.6	0.0	-17.5
Σ Δd (m)	-46.2	-83.6	108.8	13.3
$\Sigma \frac{\Delta d}{\text{length}} \times 10^6$	- 2.89	- 5.23	6.81	0.83

To verify the suspicion that something is wrong with the given measured value of line 6032-6060, a free adjustment was performed, in which both the origin and the scale constraints were "free" [Blaha, 1971]. It is expected that the variances obtained from such an adjustment would primarily reflect the geometry of the situation. In other words the variances of the various lengths would be due to the geometry of the network and free of the quality of the measured lengths. If the estimated variances of the measured lengths $(\sigma_d^{msrd})^2$ are added to those obtained from the free adjustment $(\sigma_d^{free})^2$, an estimate is obtained from the maximum expected variances of the length differences $(\sigma_{\Delta d}^{est})^2$. If an actual length difference is found to be 2-3 times greater than this estimated standard deviation, the measured length becomes suspect. The result of such an analysis is shown in Table 5.

Table 5

Adjusted - Measured Lengths (Δd) from a Free Adjustment

Line	σ_d^{free} (m)	σ_d^{msrd} (m)*	$\sigma_{\Delta d}^{est}$ (m)	Δd (m)
6002-6003	4.2	3.5	5.5	- 5.0
6006-6016	4.5	3.5	5.7	-17.2
6063-6064	4.4	4.1	6.0	2.4
6023-6060	4.4	4.6	6.4	-12.1
6032-6060	4.3	6.3	7.6	-33.1

*From Table 3.

From the table it is seen again that line 6032-6060 is out of bounds.

Another way of evaluating the effect of a scalar is through the semi-diameter of an ellipsoid best fitting the geoid resulting from a solution (see more of this in section 3.3). In this method the undulations for each station are computed (Ellipsoidal Height - Mean Sea Level Height) and, after suitable transformations for shift in origin, are compared with some standard set of undulations (in this case with those in [Rapp, 1973]). The average difference of these two sets of undulations (ΔN) is equivalent (with opposite sign) to the difference between the semidiameter of the reference ellipsoid (a = 6 378 155 m) and that of the level ellipsoid of the same flattening to which the "standard" undulations refer.

Three sets of such comparisons were performed. One with the baselines constrained with weights corresponding to the standard deviations listed in Table 3, one with all lines constrained to 1:3 M, and one with 1:30 M. Within each set the adjustment was performed with all 6000 EDM lines constrained and also without the line 6032-6060 (seven lines). The results are shown in Table 6. In addition to the semidiameter of the best-fitting level ellipsoid, the table also contains the average standard deviations of a single coordinate ($\sigma^2 = \sigma_u^2 + \sigma_v^2 + \sigma_w^2$) as well as those of the heights (σ_H) and the ratios adjusted-measured lengths/lengths: $\Sigma \frac{\Delta d}{\text{length}}$.

Table 6

Comparison of Seven- or Eight-Baseline Solutions

Solution	No.of Lines Constrained	Type of Constraint	$\Sigma\frac{\Delta d}{\text{length}}\times 10^6$	a (level ellipsoid) 6 378 000 + (m)	σ (m)	σ_H (m)
BC D12	8	as in Table 3	.81	124.1 ± 11.0	6.3	8.1
BC D 2	7		.19	118.4 ± 11.2	6.2	8.3
BC D 7	8	1:3 M	.08	128.0 ± 10.8	6.1	7.7
BC D 8	7		.04	119.7 ± 11.2	6.2	7.9
BC D 9	8	1:30 M	.02	127.0 ± 10.7	5.9	7.2
BC D10	7		.01	118.0 ± 11.2	6.0	7.3

From the table it is evident that though the varying type and number of constraints do not change significantly, the quality of the coordinates in the seven-baseline solutions (D2, D8, D10) the adjusted lengths agree much better with their measured values than in the eight-baseline solutions (D12, D7, D9). It is also seen that the inclusion of the single east-west Australian line increases the semidiameter by the unreasonable amount of 6-9 m (1-1.5 ppM) in all cases.

On the basis of the results in Table 4 - 6 and also based on other calculations not reported here, the measured value of the Australian line 6032-6060 was rejected as a useful constraint.

The high standard deviations attached to the semidiameters of the level ellipsoids in Table 6 also indicate the questionable value of only seven or eight baselines in scaling a global network regardless of their individual quality. The inclusion of height constraints in the solution is an attempt for a better scale.

3.3 Use of Constrained Ellipsoidal Heights As Scalars

The use of geodetic (ellipsoidal) heights as weighted constraints as a contribution to the scale requires a more detailed explanation (Fig. 2).

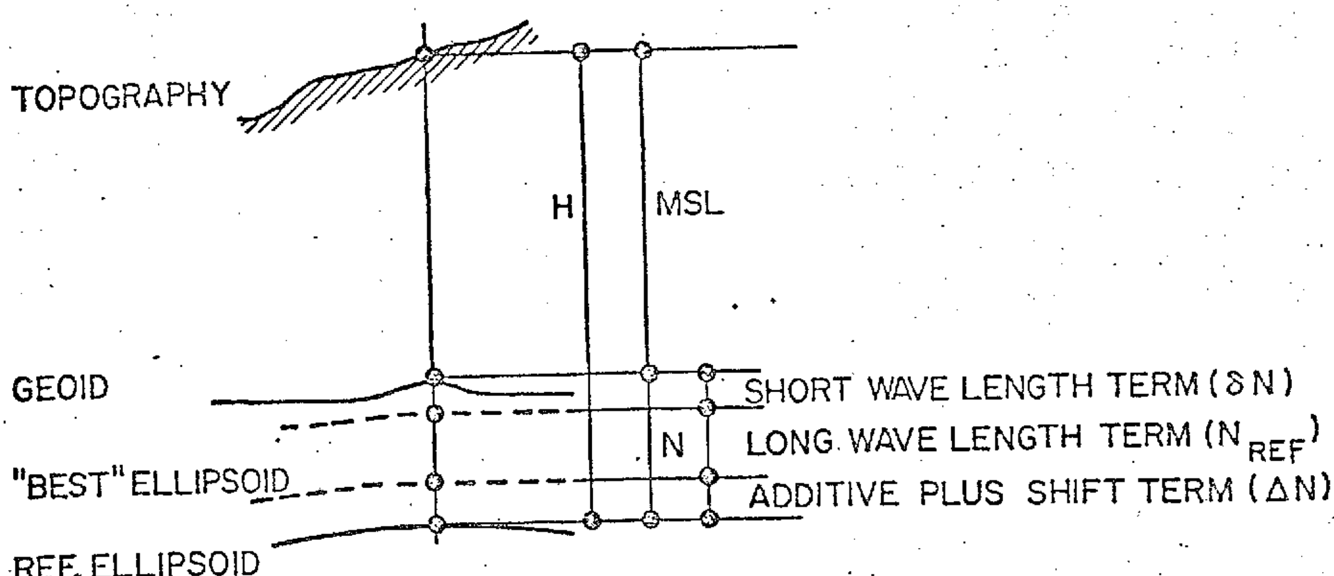

Fig. 2 Height components.

The height (H) above a geocentric reference ellipsoid has two main components: the orthometric (mean sea level) height (MSL) and the geoid undulation (N). In this geocentric case, N consists of a long-wave-length component N_{REF}, a short-wave-length term δN, and an additive part Δa. The term N_{REF} generally corresponds to regional gravitational effects and can be computed, e.g., from a truncated spherical harmonic series. The short-wave-length part δN corresponds to local gravity or mass disturbances and is generally not contained in the spherical harmonic representation. The additive part Δa is the so-called zero-degree term which may exist due to the fact that the ellipsoid may not be of the same size (though it is of the same flattening) as the "best" (mean earth) level ellipsoid to which the undulation, N_{REF}, are referenced. Since the N_{REF} undulations are, within reasonable limits, insensitive to the semidiameter of the level ellipsoid, it is difficult to define a correct value for Δa. If the reference ellipsoid is nongeocentric, as is the case in this solution, an additional height term (dH) arises due to the "shift" of the origin (ellipsoidal center) with respect to the geocenter.

Thus the geodetic height may have the following components:

$$H = MSL + N \tag{1}$$

$$N = N_{REF} + \delta N + \Delta N \tag{2}$$

where [Heiskanen and Moritz, 1967, p. 207].

$$\Delta N = \Delta a + dH = \Delta a + u_o \cos\phi \cos\lambda + v_o \cos\phi \sin\lambda + w_o \sin\phi \tag{3}$$

$$\Delta a = a \text{ (level ellipsoid)} - a \text{ (reference ellipsoid)}$$

u_o, v_o, w_o are the coordinates of the geocenter with respect to the center of the reference ellipsoid (origin)

ϕ, λ are the geodetic coordinates of the station to which H refers

In practice at most satellite tracking stations, the quantity $MSL + N_{REF}$ is well known, and generally it constitutes the largest portion of the total height above the level ellipsoid. The additive + shift term, ΔN, can be determined empirically through an iterative interpolation procedure as described later. Since $MSL + N_{REF} + \Delta N$ constitute the largest portion of the total height above the reference ellipsoid, it seems reasonable not to ignore this, admittedly partial, information on the height of the station and to include it in the adjustment as a constraint ($H_{CONSTR} = MSL + N_{REF} + \Delta N$) with such a weight that the adjustment should be able to "pull out" the only remaining component, the short-wave-length term, δN, together with possible errors in H_{CONSTR}. In this solution the standard deviations used in computing the weights vary from ±2.5 m to ±8 m depending mostly on the location of the station, from the point of view of the extent of the available surface gravity observations in the area which was included in the spherical harmonic expansion for N_{REF} [Rapp, 1973].

In trying to determine the "best" scale for the solution or, which is the same, the "best" additive term Δa, the first step is to establish the relationship between them. This problem differently stated is the determination of the relationship between the additive term and the semi-diameter of the "best" level ellipsoid to which the quantity N_{REF} refers. The meaning of the term "best" will be elaborated on later in this section. This is accomplished empirically from a set of solutions with height constraints containing different additive terms, from $\Delta a = 0$ to 30 m. The shift term dH initially is estimated from comparisons with various dynamic solutions, resulting in the coordinates u_o, v_o and w_o needed in equations (3). These solutions result in sets of geodetic heights (H_{WNi}) above the reference ellipsoid and also in sets of undulations after subtracting the MSL:

$$N_{WNi} = H_{WNi} - MSL$$

These undulations thus refer to the reference ellipsoid of a = 6 378 155 m, whose origin is set by the inner constraint. Disregarding the short-wave-length term, the relationship between the undulations N_{WNi} and N_{REF} is given by equations (2) and (3), from where, for any station and for the solution WNi:

$$(N_{WNi} - N_{REF}) - (\Delta a_i + u_{oi} \cos\phi \cos\lambda + v_{oi} \cos\phi \sin\lambda + \\ + w_{oi} \sin\phi) = 0$$

Since the quantity $(N_{WNi} - N_{REF})$ is known at all stations, the parameters Δa_i, u_{oi}, v_{oi}, w_{oi} can be calculated (iterated) from least squares adjustments for each set "i." This is the same as determining the size (scale) and the origin of the level ellipsoid which fits best the geoid defined for a given set by the undulations N_{WNi} Its size is

$$a_i = 6\ 378\ 155 + \Delta a_i$$

and its origin with respect to the origin of the reference ellipsoid is defined by the coordinates u_{oi}, v_{oi} and w_{oi}. After some iterations these coordinates hardly change from solution (set) to solution (set), regardless of the initial selection of Δa; thus the relationship between the input additive term and the resulting semidiameter, $a = f(\Delta a)$, becomes straightforward and linear.

This empirically determined relationship is shown in Fig. 3, as the dashed line drawn from the lower left corner towards the upper right. The corresponding ordinate is on the right-hand side of the diagram. The line now allows either to pick the correct initial additive term which when used in the height constraints would result in an a priori defined

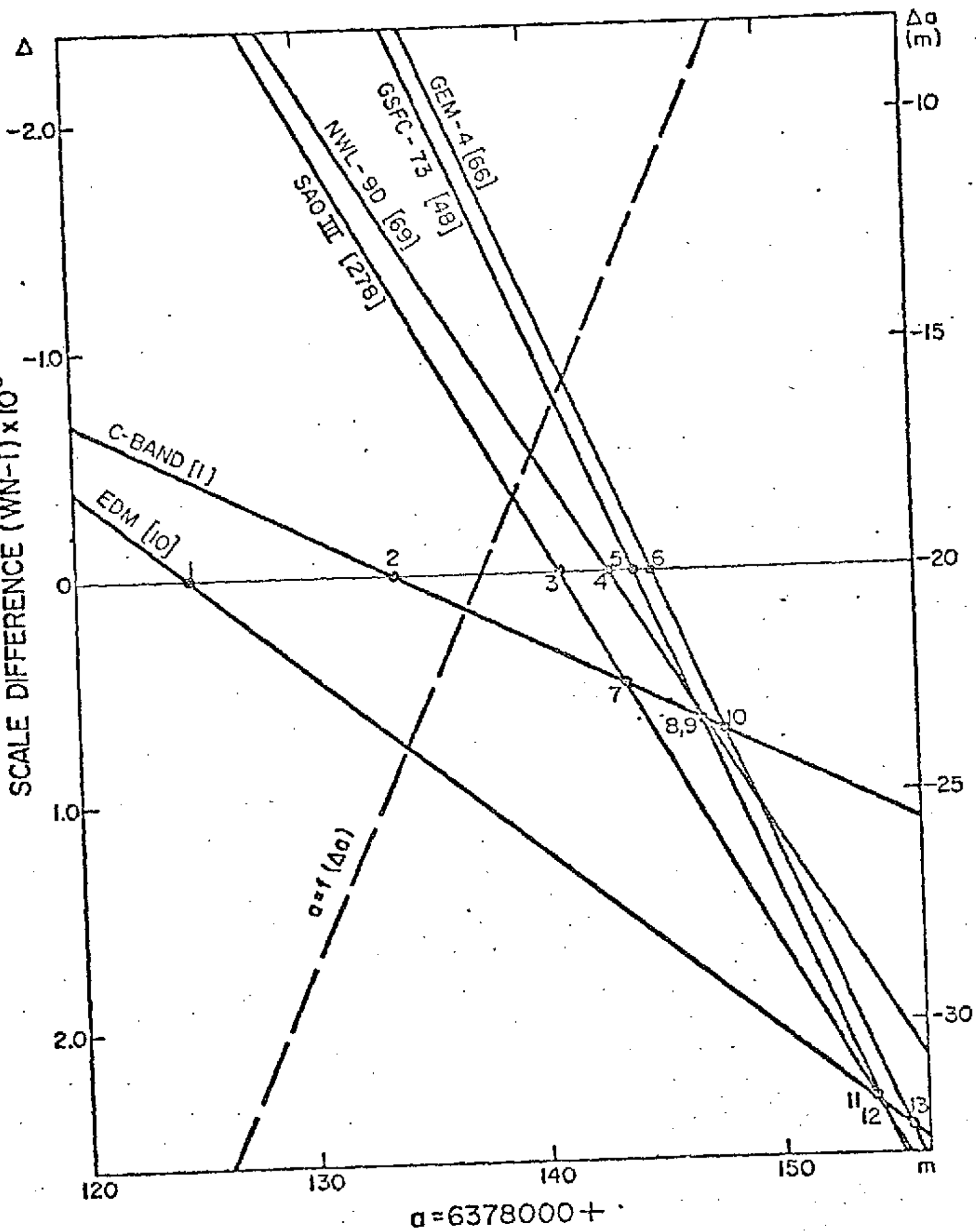

Fig. 3 Determination of scale.

semidiameter (scale), or to determine which semidiameter (scale) would correspond to an a priori defined additive term. As an example, if the semidiameter of the level ellipsoid best fitting the geoid was to be 6 378 142 m, the WN solution would require height constraints computed with an additive term of -15 m.

The next question, of course, is just how big should this desired semidiameter be. Putting it differently, what criterion should be used to select the "best" scale? If the scale was to be determined only from the EDM and C-Band baselines and/or the SECOR observations, these questions would not arise since the scale would be inherently defined. The use of weighted height constraints, as explained above, provides a unique tool to select the scale to fit some criterion. There could be several noninclusive criteria, e.g.,

(1) The lengths of the EDM baselines as computed from the adjusted coordinates of the terminal stations should be (a) exactly the same as the given lengths in Table 3, or (b) their differences should be within the limit of one (average) standard deviation, or (c) within a certain limit, e.g.,1:1,000,000, etc.

(2) Same as (1) but for the C-Band baselines.

(3) The scale difference as determined from the station coordinates of the WN solution and from the same coordinates of <u>some</u> dynamic solution should be (a) exactly zero, (b) within the limit of one standard deviation of the scale difference factor, (c) within 1:1,000,000, etc.

(4) The scale difference as determined in (3) should be within a certain limit with respect to <u>all</u> the dynamic solutions.

(5) The scale difference should be within a certain limit with respect to all the dynamic solutions <u>and</u> the EDM and C-Band baselines.

In order to be able to enforce any of the above criteria, first the relationship between the scale difference factor and the semidiameter has to be established. This is accomplished again empirically by determining the scale differences between the different WNi solutions (used to determine the function $a = f(\Delta a)$) and the EDM and C-Band baselines and the dynamic solutions NWL-9D [Anderle, 1973], SAO III [Gaposchkin et al., 1973], GEM 4 [Lerch et al., 1972], GSFC 73 [Marsh et al., 1973]. The method of calculating the scale-difference factor is described in [Kumar, 1972], and the results are shown in Fig. 3 where, with the ordinate on the left-hand side, the scale differences are plot against the semidiameters corresponding to the various Δa's used in the height constraints. The numbers on the lines indicate relative weights based on the uncertainties of the scale-difference determinations. It can be seen that the lines representing the geometric (EDM and C-Band) scale differences are much less well determined than the dynamic ones. As an example, the scale-difference factor, between the WNi solution computed with $\Delta a = -15$ m ($a = 6\ 378\ 142$ m), and the solutions NWL-9D is -0.18×10^{-6}; the GEM 4 is -0.68×10^{-6} (the dynamic scales are larger). Also, the lengths of the EDM baselines from the adjustment differ from their directly measured values by 1.38×10^{-6} (the measured values are smaller).

The diagram is used by recognising the importance of the various intersection points, marked by numbers. For example, point 1 illustrates the fact that if the semidiameter of the level ellipsoid was 6 378 125 m, the difference between the adjusted chord lengths and their given values would be zero; point 4 shows that with an $a = 6\ 378\ 143$ m there would be no scale difference between WNi and NWL-9D. Fourteen similar intersection points are listed in Table 7 with weights and interpretation.

Table 7

Determination of Scale

Point	Interpretation*	Weight	a (m)	Weighted Mean a (m)
1	WN = EDM	10	6 378 125.0	6 378 125.8 (from points 1 and 2)
2	WN = C-Band	1	6 378 133.7	
3	WN = SAO III	278	6 378 140.8	6 378 141.7 (from points 1 - 6)
4	WN = NWL 9D	69	6 378 143.0	6 378 142.0 (from points 3 - 6)
5	WN = GSFC 73	66	6 378 144.9	
6	WN = GEM 4	48	6 378 144.1	
7	C-Band = SAO III	1	6 378 143.6	6 378 142.7 (from points 1 - 14)
8	C-Band = GSFC 73	1	6 378 146.8	
9	C-Band = NWL 9D	1	6 378 147.1	
10	C-Band = GEM 4	1	6 378 147.8	
11	EDM = SAO III	10	6 378 153.7	
12	EDM = GSFC 73	8	6 378 154.0	
13	EDM = GEM 4	9	6 378 155.2	
14	EDM = NWL 9D	9	6 378 160.5	

From the table it is immediately clear that taking the weighted mean of the intersection points from the "geometric" scalars (points 1 and 2), the "best" semidiameter is 6 378 125.8 m, while from the "dynamic" lines (points 3 - 6) it is 6 378 142.0 m. The difference of some 16 m, or about 2.5 parts in a million, seems to be real but unexplained at this time. The combined weighted mean from points 1 - 6 is 6 378 141.7 m; while from all the points (1 - 14), it is 6 378 142.7 m.

For the solution reported here (WN14), the criterion for the scale is (5) above, i.e., that the scale should correspond well to all geometric and dynamic information available at present. Based on the above numbers and on previously published parameters, a = 6 378 142 m was selected. This then requires an adjustment in which the scale is defined, in addition to the SECOR, EDM and C-Band observations, through height constraints with the initial additive constant $\Delta a = -15$ m. As can be seen from Fig. 3 at this semidiameter the maximum scale difference expected between WN14 and any of the dynamic solutions is about 0.8×10^{-6}, and with respect to the EDM about 1.4×10^{-6} or 1:700,000 which is about the average standard deviation of the EDM baselines. Using this scale the resulting geoid undulations

$$N = H_{WN14} - MSL - \Delta N \tag{4}$$

with

$$\Delta N \text{ (meters)} = -13 - 23.2 \cos\phi \cos\lambda - 2.9 \cos\phi \sin\lambda + 2.7 \sin\phi$$

are consistent with dynamically computed ones when the following set of constants defining the gravity field of the level ellipsoid are used [Heiskanen and Moritz, 1967, p. 64]:

$f = 1/298.25$ (flattening)

$\omega = 0.72921151467 \times 10^{-4} \text{sec}^{-1}$ (rotational velocity)

$a = 6\ 378\ 142$ m

$W_o = 6\ 263\ 688.00$ kgal m (geopotential on the geoid)

Derived from these are the following parameters:

$k^2M = 3.98600922 \times 10^{14}\ m^3\ sec^{-1}$ (gravitational constant x earth mass)

$\gamma_e = 978.03226$ cm sec^{-2} (equatorial normal gravity)

$J_2 = 1\ 082.6863 \times 10^{-6}$ (second-degree harmonic)

All the above constants are in good agreement with their current best estimates. The parameters in equation (4) ($\Delta a = -13 \pm 0.7$ m, $u_o = -23.2 \pm 0.9$ m, $v_o = -2.9 \pm 0.8$ m, $w_o = 2.7 \pm 1.2$ m) are the result of fitting an ellipsoid to the WN14 geoid as explained earlier in this section, and they represent the size and the position of the best fitting level ellipsoid with respect to the reference ellipsoid (of the same flattening). In case of a good global station distribution the center of this level ellipsoid is the "geometric" center of the geoid. If this point is assumed to be identical with the center of mass than the above coordinates may be viewed as its coordinates with respect to the origin of the reference ellipsoid, and with opposite signs they can be used to shift the WN14 coordinates to the geocenter:

$$
\begin{aligned}
u \text{ (geocentric)} &= u_{WN14} + 23.2 \text{ m} \\
v \text{ (geocentric)} &= v_{WN14} + 2.9 \text{ m} \\
w \text{ (geocentric)} &= w_{WN14} - 2.7 \text{ m}
\end{aligned} \qquad (5)
$$

It should be pointed out again that the selection of the semidiameter 6 378 142 m was arbitrary. Had the lowest extremity in Table 7 been chosen (6 378 125 m), the gravitational parameters (keeping f, ω, and the geoidal undulations the same) still would not become completely unreasonable:

$$W_o = 6\ 263\ 705.35 \text{ kgal m}$$

$$k^2M = 3.98600968 \times 10^{14} \text{ m}^3 \text{ sec}^{-1}$$

$$\gamma_e = 978.03762 \text{ cm sec}^{-2}$$

$$J_2 = 1082.6956 \times 10^{-6}$$

Thus the question of what is the "best" semidiameter still needs to be answered.

4. COMPARISON OF THE RESULTS

4.1 Comparisons with Geometric Information

In addition to solution WN14, two other adjustments were also performed with the same data. The only differences were that in one of them (WN12) the weighted height constraints were not applied; thus the scale is defined through the SECOR, EDM and C-Band data. In the other (WN16), the EDM and C-Band lengths were not entered as weighted constraints; thus the scale is through the SECOR and the weighted height constraints.

Table 8 contains the differences between the adjusted and given chord lengths (Table 3) from the three solutions. The lines originating from Sta. 4742 (Kauai) are not listed for reasons explained earlier. Comparing solutions WN14 and WN12 the effect of including the heights is not

Table 8

Chord Length Comparisons (Solutions WN12, 14 and 16)

Type	Line	Adjusted – Given Length					
		WN12		WN14		WN16	
		m	ppM	m	ppM	m	ppM
EDM	6002 – 6003	8.3 ± 2.5	2.38	2.7 ± 2.3	0.78	5.9 ± 3.0	1.70
	6003 – 6111	2.7 ± 1.4	1.90	2.3 ± 1.4	1.60	11.4 ± 3.1	8.00
	6006 – 6065	7.7 ± 2.1	3.13	6.1 ± 2.0	2.47	19.9 ± 3.5	8.13
	6016 – 6065	– 2.8 ± 1.3	2.30	– 2.9 ± 1.3	2.47	–18.9 ± 3.4	15.87
	6006 – 6016	2.7 ± 2.2	0.77	1.3 ± 2.1	0.37	1.6 ± 3.3	0.46
	6063 – 6064	13.7 ± 2.4	3.94	10.6 ± 2.3	3.03	15.2 ± 2.8	4.37
	6023 – 6060	7.9 ± 3.1	3.42	5.9 ± 3.0	2.55	9.6 ± 3.8	4.16
	6032 – 6060*	– 2.4 ± 3.9	0.76	– 4.5 ± 3.6	1.42	– 2.9 ± 3.7	0.92
	3861 – 7043	2.2 ± 1.8	1.44	1.5 ± 1.8	0.99	7.6 ± 3.7	5.00
C-Band	4082 – 4050*	26.5 ± 6.9	2.42	– 5.2 ± 3.9	0.48	– 4.2 ± 4.0	0.39
	4082 – 4740	2.0 ± 2.7	1.25	1.3 ± 2.7	1.90	6.6 ± 5.0	4.13
	4082 – 4081	3.0 ± 2.3	2.40	2.3 ± 2.3	0.79	17.9 ± 6.2	14.49
	4082 – 4061	– 0.4 ± 3.6	0.19	– 1.5 ± 3.6	0.65	2.1 ± 6.1	0.93
Average	EDM		2.22		1.74		5.40
	C-Band		1.56		0.96		4.98
	All		2.02		1.50		5.27

*Not constrained in WN12 and WN14.

very significant. The average length discrepancy decreases 0.48×10^{-6} in case of the EDM, and 0.60×10^{-6} in the C-Band case, both numbers being within the noise level. At first glance the difference between WN14 and WN16 seems to be significant since the average length discrepancy increases by about 4×10^{-6} or 1:250,000 for both types of observations. Close inspection, however, reveals that though the inclusion of the EDM and C-Band chords in the solution improves the positions of stations 6111 (Wrightwood), 6065 (H. Peissenberg) and 4081 (Grand Turk), it does not otherwise contribute to the overall scale determination significantly. If the above-mentioned stations are left out from the comparison, the average length discrepancies in the WN16 solution decrease to 2.76×10^{-6} for the EDM and 1.81×10^{-6} for the C-Band, both within noise level from WN14 (about 1×10^{-6}).

The above conclusion is also strengthened by the content of Table 9 where the average standard deviations of the coordinates and the heights are compared from the three solutions. It is seen that while the inclusion

Table 9

Standard Deviation Comparisons
(Solutions WN12, 14 and 16)

Solution	Constituent Networks								WN_i	
	BC		SECOR		MPS		SA			
	σ	σ_H	σ	σ_H	σ	σ_H	σ	σ_H	σ	σ_H
WN12	4.4	5.0	4.2	4.8	6.9	7.6	5.2	5.9	5.5	6.2
WN14	3.5	3.2	2.8	2.4	4.8	2.9	4.1	3.0	3.9	2.9
WN16	3.5	3.2	2.8	2.4	4.9	2.9	4.1	3.0	4.0	2.9

All units in meters.

of the weighted heights decreases the standard deviations significantly, the exclusion of the geometric scalars hardly changes the results.

In the tables the rotations ω, ψ and ε are about the w, v and u axes respectively. The unit in the variance-covariance matrix, for the elements corresponding to the rotations, is radian squared.

4.2 Comparisons with Dynamic Solutions

Table 10 is a compilation of transformation parameters between the WN coordinates and those from the dynamic solutions NWL-9D, SAO III, GEM-4 and GSFC-73. The method of computing the parameters is described in [Kumar, 1972]. In the table the positive angles ω, ψ and ε are counter-clockwise rotations about the w, v and u axes respectively, as viewed from the end of the positive axis. The scale difference factor Δ is in units of ppM. In the transformations the variances of both sets of the coordinates are taken into account. Taking the variances of the WN solutions as standard, those of the dynamic solutions are scaled by the weight factors indicated. These numbers are also indicative of the overoptimism over the quality of some of the published solutions. For example, a weight factor of 25 would indicate that the published standard deviations of a given solution need to be multiplied by $\sqrt{25} = 5$.

As it is seen there is a good agreement between the translational elements Δu-s and Δv-s of the main (all stations inclusive) dynamic solutions and a discrepancy of about 8.5 ± 1.7 m with respect to the geometric values (see equation 5). The largest discrepancy occurs in the Δw components, where there seems to be a 12.3 ± 2.1 m difference between the SAO III and the GEM-4 solutions. Eliminating the SAO III value, all Δw's, including the geometric one, are within the noise level. The weighted mean shifts

Table 10

Relationships Between Various Dynamic and the WN Systems
(Dynamic - WN14)

Solution	NWL-9D			SAO III			GEM-4	GSFC-73
Sta. Considered	5000	6000	all	6000	9000	all	all	all
No. Stations	12	22	32	47	22	73	30	26
Weight Factor*	1.5	7.75	∿ 4	2	2	2	50	22
Δu (m)	15.6 ±1.6	16.8 ±1.1	15.9 ±1.0	16.8 ±1.5	10.7 ±2.1	13.9 ±1.3	14.5 ±1.6	13.7 ±1.5
Δv (m)	13.1 ±1.5	9.6 ±1.1	10.3 ±1.0	12.8 ±1.5	13.6 ±2.2	13.6 ±1.3	11.6 ±1.6	12.9 ±1.4
Δw (m)	- 7.8 ±2.0	- 3.2 ±1.1	- 3.4 ±1.1	- 5.2 ±1.5	-15.7 ±2.3	-10.4 ±1.3	1.9 ±1.7	- 1.7 ±1.9
$\Delta(10^{-6})$	0.74±0.15	0.26±0.05	0.29±0.04	- 0.50±0.05	0.74±0.15	- 0.17±0.04	0.93±0.11	0.96±0.11
$\omega('')$	0.73±0.03	0.70±0.01	0.71±0.01	0.51±0.02	0.26±0.03	0.37±0.01	- 0.02±0.02	- 0.38±0.02
$\psi('')$	- 0.11±0.04	- 0.15±0.01	- 0.15±0.01	0.15±0.02	0.08±0.04	0.15±0.01	0.12±0.03	0.19±0.03
$\epsilon('')$	0.23±0.07	- 0.17±0.01	- 0.14±0.01	- 0.18±0.02	0.07±0.03	- 0.03±0.01	0.17±0.02	0.24±0.03
σ_0^2	0.65	0.91	0.87	0.83	1.20	1.14	1.11	1.09

*Weight Factor = $\sigma^2_{0,i}/\sigma^2_{0,WN14}$

from the main dynamic solutions (excluding Δw from SAO III), or the coordinates of the geocenter with respect to the WN14 origin, are listed in Table 11.

Table 11

Shifts to the Geocenter (Solution WN14)

Source	u_0 (m)	v_0 (m)	w_0 (m)	r_0 (m)
1. Dynamic Comparison	14.8 ±1.4	11.8 ±1.3	-1.8 ±1.6	18.9 ±1.9
2. Geometric Fit (equation (5))	23.2 ±0.9	2.9 ±0.8	-2.7 ±1.2	23.4 ±1.2
3. Weighted Mean of 1 & 2	20.7 ±1.2	5.3 ±1.1	-2.4 ±1.4	21.4 ±1.6
4. JPL/DSN				25.9 ±2.5

The quantity $r_0 = \sqrt{u_0^2 + v_0^2}$ is distance of the WN14 origin from the rotation axis of the earth. Calculating the same number from the JPL-LS 37 coordinates of the Deep Space Network (stations DSN1 = 4711, DSN2 = 4712, DSN4 = 4714, DSN6 = 4742 and DSN7 = 4751) as published in [Gaposchkin et al., 1973], one gets r_0 = 25.9 ±2.5 m, which value is nearest to the one calculated from the geometric fit.

The differences in scale between the dynamic solutions are significant (see Fig. 3 for comparison). The largest discrepancy is between the SAO III and GSFC-73 with $\Delta = (1.13 \pm 0.12) \times 10^{-6}$, which is larger than what one would expect from the noise. The other dynamic scales are within near noise level and, on the average, differ from the scale of the WN14 solution by

$$\Delta = (0.12 \pm 0.08) \times 10^{-6}$$

or about one part in 8.3 million.

The largest discrepancies occur in the orientation of the various dynamic systems with respect to each other and to WN14. In the rotation about the w axis (ω), the largest difference occurs between the NWL-9D and the GSFC-73 solutions, where $\omega = 1\overset{''}{.}1$, or about 34 m on the equator (Fig. 4). The other differences are smaller but are significant. These rotations may be partly due to the definition of the zero meridian in the case of purely electronic systems (e.g., Doppler), partly to the various definitions of the vernal equinox in the star catalogs used, and also to its motion with respect to inertial space, in case of optical observations. The latter alone requires a correction to the FK4 right ascensions amounting to $+0\overset{''}{.}65$ at 1960.0, changing with a rate of $+1\overset{''}{.}36$ per century [Martin and Van Flandern, 1970].

The rotations about the axes u and v are even more confusing. Fig. 5 illustrates the situation at the pole. The weighted means of the dynamic solutions are $\psi = 0\overset{''}{.}02 \pm 0\overset{''}{.}02$ and $\varepsilon = -0\overset{''}{.}04 \pm 0\overset{''}{.}02$. The discrepancy between the poles as determined separately from the SAO III 6000 stations and then from the 9000 stations is unexplained at this time. It is interesting to note that the weighted mean pole and zero meridian positions computed from the dynamic solutions hardly differ from those of the WN14 solution.

The only general conclusion that one can draw from the rotation parameters is that the coordinate systems used in the dynamic solutions need to be more carefully defined and conditions enforcing these definitions more strongly applied than evidenced from the solutions discussed.

4.3 Comparisons with Geodetic Datums

Table 12 is a summary of datum descriptions. Table 13 summarizes the relationships between the various geodetic datums and the WN14 system for those datums where stations were located.

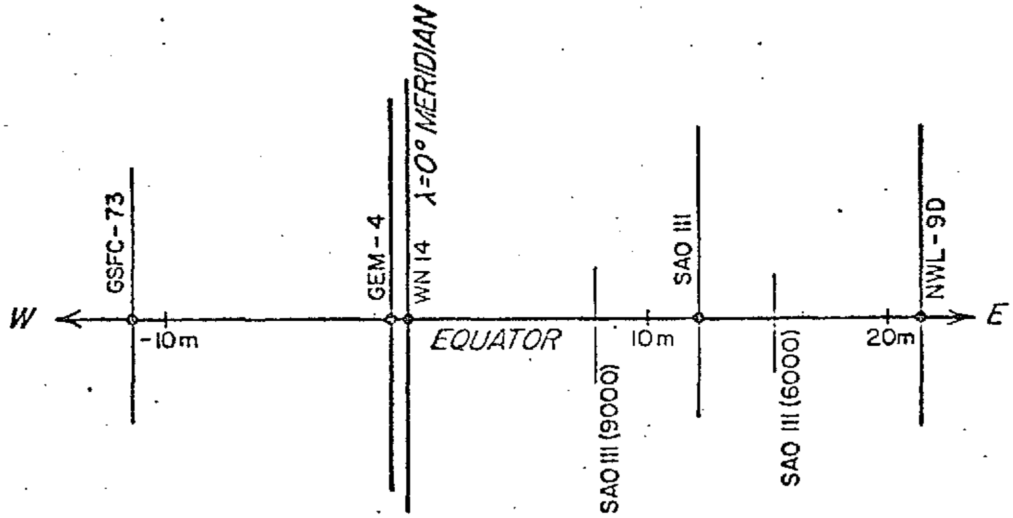

Fig. 4 Dynamic zero meridians relative to the WN14 zero meridian.

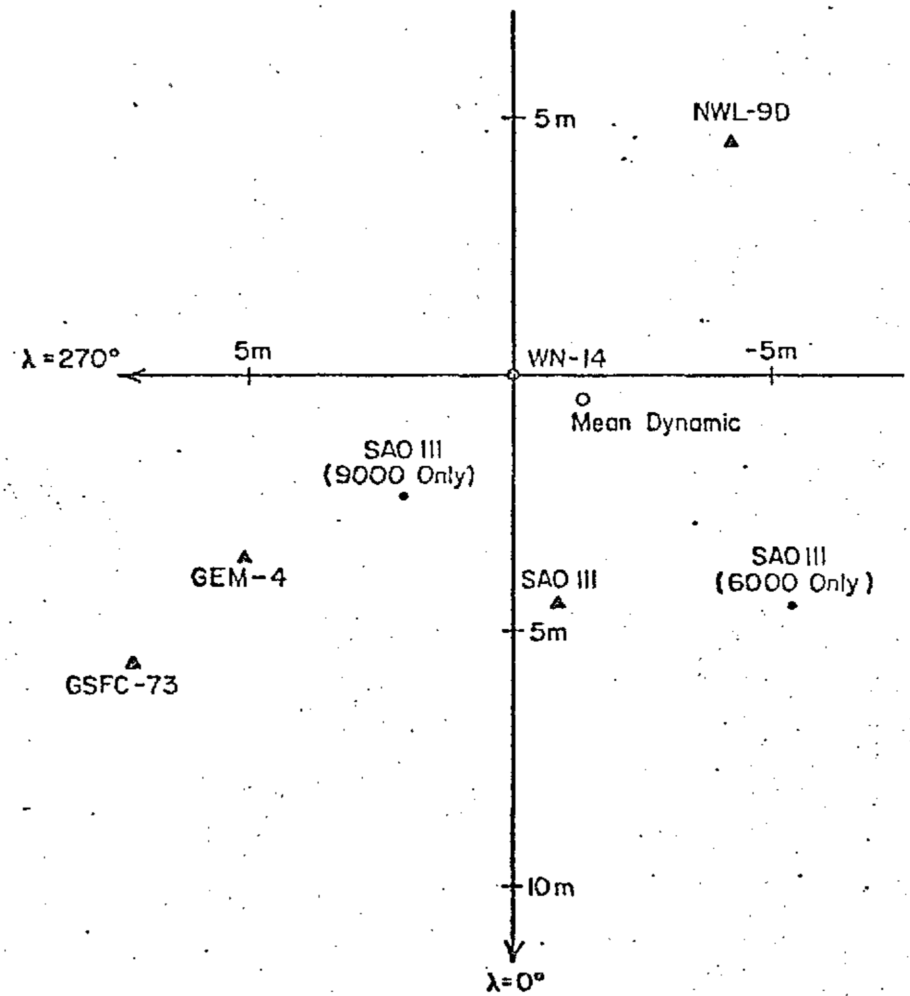

Fig. 5 Dynamic pole positions relative to the WN14 pole.

Table 12

Geodetic Datums

Code	Datum	Ellipsoid	Origin	Latitude	Longitude
1	Adindan (Ethiopia)	Clarke 1880	STATION Z5 ADINDAN	22°10'07"110	31°29'21"603
2	American Samoa 1962	Clarke 1866	BETTY 13 ECC	-14 20 08.341	189 17 07.750
3	Arc-Cape (South Africa)	Clarke 1880	Buffelsfontein	-33 59 32.000	25 30 44.622
4	Argentine	International	Campo Inchauspe	-35 58 17	297 49 48
5	Ascension Island 1958	International	Mean of three stations	-07 57	345 37
6	Australian Geodetic	Australian National	Johnston Memorial Cairn	-25 56 54.55	133 12 30.08
7	Bermuda 1957	Clarke 1866	FT. GEORGE B 1937	32 22 44.360	295 19 01.890
8	Berne 1898	Bessel	Berne Observatory	46 57 08.660	07 26 22.335
9	Betio Island, 1966	International	1966 SECOR ASTRO	01 21 42.03	172 55 47.90
10	Camp Area Astro 1961-62 USGS	International	CAMP AREA ASTRO	-77 50 52.521	166 40 13.753
11	Canton Astro 1966	International	1966 CANTON SECOR ASTRO	-02 46 28.99	188 16 43.47
12	Christmas Island Astro 1967	International	SAT.TRI.STA. 059 RM3	02 00 35.91	202 35 21.82
13	Chua Astro (Brazil-Geodetic)	International	CHUA	-19 45 41.16	311 53 52.44
14	Corrego Alegre (Brazil-Mapping)	International	CORREGO ALEGRE	-19 50 15.140	311 02 17.250
15	Easter Island 1967 Astro	International	SATRIG RM No. 1	-27 10 39.95	250 34 16.81
16	European	International	Helmert Tower	52 22 51.45	13 03 58.74
17	Graciosa Island (Azores)	International	SW BASE	39 03 54.934	331 57 36.118
18	Gizo, Provisional DOS	International	GUX 1	-09 27 05.272	159 58 31.752
19	Guam	Clarke 1866	TOGCHA LEE NO. 7	13 22 38.49	144 45 51.56
20	Heard Astro 1969	International	INTSATRIG 0044 ASTRO	-53 01 11.68	73 23 22.64
21	Iben Astro, Navy 1947 (Truk)	Clarke 1866	IBEN ASTRO	07 29 13.05	151 49 44.42
22	Indian	Everest	Kalianpur	24 07 11.26	77 39 17.57
23	Isla Socorro Astro	Clarke 1866	Station 038	18 43 44.93	249 02 39.28
24	Johnston Island 1961	International	JOHNSTON ISLAND 1961	16 44 49.729	190 29 04.781
25	Kusaie, Astro 1962, 1965	International	ALLEN SODANO LIGHT	05 21 48.80	162 58 03.28
26	Luzon 1911 (Philippines)	Clarke 1866	BALANCAN	13 33 41.000	121 52 03.000
27	Midway Astro 1961	International	MIDWAY ASTRO 1961	28 11 34.50	182 36 24.28
28	New Zealand 1949	International	PAPATAHI	-41 19 08.900	175 02 51.000
29	North American 1927	Clarke 1866	MEADES RANCH	39 13 26.686	261 27 29.494
30	*NAD 1927 (Cape Canaveral)	Clarke 1866	CENTRAL	28 29 32.364	279 25 21.230
31	*NAD 1927 (White Sands)	Clarke 1866	KENT 1909	32 30 27.079	253 31 01.306
32	Old Bavarian	Bessel	Munich	48 08 20.000	11 34 26.483
33	Old Hawaiian	Clarke 1866	OAHU WEST BASE	21 18 13.89	202 09 04.20
34	Ordnance Survey G.B. 1936	Airy	Herstmonceux	50 51 55.271	00 20 45.882
35	Pico de las Nieves (Canaries)	International	PICO DE LAS NIEVES	27 57 41.273	344 25 49.476
36	Pitcairn Island Astro	International	PITCAIRN ASTRO 1967	-25 04 06.97	229 53 12.17
37	Potsdam	Bessel	Helmert Tower	52 22 53.954	13 04 01.153
38	Provisional S.American 1956	International	LA CANOA	08 34 17.17	296 08 25.12
39	Provisional S. Chile 1963	International	HITO XVIII	-53 57 07.76	291 23 28.76
40	Pulkovo 1942	Krassovski	Pulkovo Observatory	59 46 18.55	30 19 42.09
41	South American 1969	South American 1969	CHUA	-19 45 41.653	311 53 55.936
42	Southeast Island (Mahe)	Clarke 1880		-04 40 39.460	55 32 00.166
43	South Georgia Astro	International	ISTS 061 ASTRO POINT 1968	-54 16 38.93	323 30 43.97
44	Swallow Islands (Solomons)	International	1966 SECOR ASTRO	-10 18 21.42	166 17 56.79
45	Tananarive	International	Tananarive Observatory	-18 55 02.10	47 33 06.75
46	Tokyo	Bessel	Tokyo Observatory (old)	35 39 17.51	139 44 40.50
47	Tristan Astro 1968	International	INTSATRIG 069 RM No. 2	-37 03 26.79	347 40 53.21
48	Viti Levu 1916 (Fiji)	Clarke 1880	MONAVATU (latitude only) SUVA (longitude only)	-17 53 28.285	178 25 35.835
49	Wake Island, Astronomic 1952	International	ASTRO 1952	19 17 19.991	166 38 46.294
50	Yof Astro 1967 (Dakar)	Clarke 1880	YOF ASTRO 1967	14 44 41.62	342 30 52.98
51	Palmer Astro 1969	International	ISTS 050	-64 46 35.71	295 56 39.53
52	Eftate	International	Belle Vue IGN	-17 44 17.400	168 20 33.250

*Local datums of special purpose, based on NAD 1927 values for the origin stations.

Table 13

Relationship Between Various Geodetic Datums and the WN System (Datum - WN14)

Datum No.	Datum Name[1]	No. of Stations	Δu (m)*	Δv (m)*	Δw (m)*	ω (")**	ψ (")**	ϵ (")**	Δ ($\times 10^6$)
1	Adindan (Ethiopia)	2	184 ±19	21 ±11	-200 ± 6				
2	American Samoa 1962	1	119 ± 8	-105 ± 8	-413 ±10				
3	Arc Cape (South Africa)	1	152 ± 7	126 ± 7	298 ±10				
5	Ascension Island 1958	1	227 ± 7	- 93 ± 7	- 58 ± 8				
6	Australian Geodetic	3	118.2± 5.0	41.1± 6.2	-121.0± 6.9	1.03±0.18	0.99±0.18	-0.25±0.22	-1.20±0.71
10	Camp Area Astro 1961/62(USGS)	1	111 ±10	148 ± 9	-238 ±10				
12	Christmas Island Astro 1967	1	-115 ± 9	-224 ±12	529 ± 8				
15	Easter Island Astro 1967	1	-182 ±10	-138 ±10	-128 ±11				
16	European-50 (W)[3]	11	133.3± 9.5	114.2±15.9	152.2± 9.2	-1.76±0.38	0.01±0.31	-0.38±0.44	-7.30±1.14
	European-50 (All stations)[3]	16	134.3± 9.1	152.7± 8.0	144.6± 8.8	-0.41±0.20	0.27±0.30	-0.51±0.22	-7.24±0.88
17	Graciosa Island (Azores)	1	123 ±17	-147 ± 9	37 ±17				
20	Heard Astro 1969	1	182 ±12	56 ±12	-114 ±14				
22	Indian[4]	1	-165 ±17	-711 ±10	-228 ±11				
23	Isla Socoro Astro	1	-134 ±12	-206 ± 7	-503 ± 9				
24	Johnston Island 1961	1	-161 ±13	51 ±25	211 ±13				
26	Luzon 1911 (Philippines)	1	151 ±10	51 ± 7	111 ± 8				
27	Midway Astro 1961	1	-377 ± 7	84 ± 7	-279 ± 9				

*If (Datum - Geocenter) is sought add to the tabulated values of Δu, Δv, Δw the respective quantities -21m, -5 m, 2 m (see Table 5.4-6).

**ω, ψ, ϵ when positive, represent counterclockwise rotations about the respective w, v, u axes, as viewed from the end of the positive axis.

Table 13 (cont'd)

Datum No.	Datum Name[1]	No. of stations	Δu (m)*	Δv (m)*	Δw (m)*	ω (″)**	ψ (″)**	ε (″)	Δ (×10⁶)
28	New Zealand 1949	1	- 61 ± 8	41 ± 9	-192 ± 9				
29	North American 1927 (W)[5]	8	30.6± 7.3	-170.3± 4.5	-134.9± 6.8	0.21±0.20	0.59±0.21	-0.45±0.23	-7.91±0.45
	North American 1927 (E)[6]	13	56.4± 6.9	-144.6± 4.4	-196.4± 4.3	1.01±0.19	-0.01±0.16	0.54±0.14	2.15±0.62
	North American (All Stations)[7]	21	57.1± 2.2	-147.9± 2.6	-187.5± 2.9	0.86±0.06	0.23±0.06	0.33±0.11	0.80±0.27
36	Pitcairn Island Astro	1	-167 ±12	-168 ±11	- 60 ±11				
39	Provisional South Chile 1963	1	0 ± 8	-196 ± 8	- 93 ± 9				
41	South American 1969[3]	10	54.4± 5.5	30.0± 4.8	42.9± 4.9	-0.63±0.17	0.17±0.12	-0.12±0.13	6.07±0.59
42	Southeast Island (Mahe)	1	54 ± 8	186 ± 8	272 ± 9				
43	South Georgia Astro	1	820 ± 8	-101 ±11	291 ±11				
46	Tokyo	1	183 ±10	-506 ± 9	-686 ± 9				
47	Tristan Astro 1968	1	654 ±14	-420 ±11	622 ±13				
49	Wake Island Astronomic 1952	1	-260 ± 7	67 ±12	-140 ± 8				
50	Yof Astro 1967 (Dakar)	1	55 ± 6	-143 ± 7	- 95 ± 7				
51	Palmer Astro 1969	1	-218 ± 9	- 8 ±12	-226 ±12				

*If (Datum - Geocenter) is sought add to the tabulated values of Δu, Δv, Δw the respective quantities -21m, -5 m, 2 m (see Table 5.4-6).

**ω, ψ, ε when positive, represent counterclockwise rotations about the respective w, v, u axes, as viewed from the end of the positive axis.

Table 13 (cont'd)

[1] See Table 3.1-3 for datum description and other related information.

[2] Stations included are Tromso (6006), Catania (6016), Hohenpeissenberg (6065), Wippolder (8009), Zimmerwald (8010), Haute Provence (8015), Nice (8019), Meudon (8030), San Fernando (9004), Dionysos (9091) and Harestua (9426).

[3] Stations included are as in #2 and Mashhad (6015), Malvern (8011), Naini Tal (9006), Shiraz (9008) and Riga (9431).

[4] Based on p. 70, Bulletin Geodesique, 107, 1973.

[5] Stations included are Goldstone (1030), Colorado Springs (3400), Vandenberg AFB (4280), Wrightwood II (6134), Moses Lake (6003), Edinburg (7036), Denver (7045) and Organ Pass (9001).

[6] Stations included are Blossom Point (1021), Fort Myers (1022), E. Grand Forks (1034), Rosman (1042), Bedford (3401), Semmes (3402), Hunter AFB (3648), Aberdeen (3657), Homestead (3861), Beltsville (6002), Greenbelt (7043), Jupiter (7072) and Sudbury (7075).

[7] Stations included are as in #4 and #5 above.

[8] Stations included are Brasilia (3414), Asunction (3431), Bogota (3477), Paramaribo (6008), Quito (6009), Villa Dolores (6019), Natal (6067), Arequipa (9007), Curacao (9009) and Comodoro Rivadavia (9031).

5. CARTESIAN COORDINATES FROM SOLUTIONS WN12 AND WN14

Table 14 is a summary of the Cartesian coordinates of solutions WN12 and WN14. As mentioned earlier the former differs from the latter only in that in it the heights are not constrained. The resulting scale in WN12 is such that when the coordinates are transformed to a geocentric rotational ellipsoid of a = 6 378 154 m and 1/f = 298.2495, they produce geoid undulations consistent with dynamically determined ones with $k^2M = 3.98600891 \times 10^{14}$ m^3 sec^{-2} and $\gamma_e = 978.02847$ cm sec^{-2}. Derived from these constants are the values $W_0 = 6\ 263\ 675.76$ kgal m and $J_2 = 1082.6797 \times 10^{-6}$. These values together with those mentioned at the end of section 3.3 seem to be the extreme limits within which the truce must lie, provided that the dynamically determined undulations are correct.

Comparisons with geoid undulations from satellite and surface gravimetric solutions in case of the WN14 solution show an rms residual of ±6.1, with an average of only -0.3 m. Similar comparison with the WN12 solution, where the heights are not constrained, shows that the rms of the residuals is ±16.1 m, and the average -0.2 m.

Table 14

Summary of Cartesian Coordinates (Solutions WN12 and WN14)

STATION		SOLUTION WN-12						SOLUTION WN-14					
NO	NAME	U	V	W	σ_u	σ_v	σ_w	U	V	W	σ_u	σ_v	σ_w
1021	BLOSSOM POINT	1110021.8	-4876331.7	3942970.9	3.1	4.0	4.2	1110023.1	-4876323.4	3942963.9	2.8	2.6	2.8
1022	FORT MYERS	807850.8	-5652004.0	2833509.0	2.6	3.3	3.3	807851.9	-5651989.6	2833500.2	2.2	1.9	2.3
1030	GOLDSTONE	-2357249.2	-4646346.4	3668312.5	6.1	4.4	4.7	-2357242.9	-4646338.5	3668306.8	5.6	3.3	3.2
1032	ST. JOHN'S	2602704.3	-3419179.7	4697621.1	49.1	89.5	29.9	2602688.6	-3419228.9	4697637.3	39.3	46.7	13.8
1033	FAIRBANKS	-2299292.3	-1445690.5	5751823.3	7.5	10.0	10.5	-2299282.6	-1445693.7	5751811.6	6.9	9.7	5.7
1034	E. GRAND FORKS	-521700.3	-4242074.9	4718726.5	3.5	4.0	4.4	-521704.5	-4242064.3	4718716.8	3.1	3.0	2.7
1042	ROSMAN	647495.9	-5177948.0	3656714.4	3.1	3.6	4.0	647497.5	-5177935.6	3656705.9	2.8	2.4	2.8
3106	ANTIGUA	2881840.5	-5372180.7	1868540.5	4.1	4.6	4.9	2881838.3	-5372164.6	1868538.6	3.7	3.3	4.3
3334	STONEVILLE	-84969.1	-5327986.3	3493434.3	15.6	14.0	10.8	-84963.8	-5327974.9	3493428.3	13.6	6.8	9.0
3400	COLORADO SPRINGS	-1275239.4	-4798062.9	3994229.5	16.3	12.4	8.6	-1275207.2	-4798029.3	3994208.3	9.1	5.1	5.7
3401	BEDFORD	1513134.8	-4463580.1	4283061.2	3.5	5.3	4.6	1513136.1	-4463576.8	4283055.8	3.2	3.4	3.0
3402	SEMMES	167256.1	-5481980.4	3245042.6	4.2	4.3	4.6	167259.7	-5481971.0	3245037.0	3.9	2.8	3.5
3404	SWAN ISLAND	642485.7	-6053942.4	1895690.5	5.0	5.3	5.5	642491.4	-6053940.3	1895688.6	4.7	3.7	4.9
3405	GRAND TURK	1919482.1	-5621096.5	2315780.1	3.6	5.6	4.9	1919482.9	-5621088.1	2315775.3	3.3	3.5	4.0
3406	CURACAO	2251802.9	-5816929.0	1327197.4	2.8	3.5	3.8	2251800.2	-5816912.9	1327191.1	2.4	2.1	3.4
3407	TRINIDAD	2979892.9	-5513532.6	1181126.8	5.2	5.1	5.9	2979891.1	-5513530.9	1181129.3	4.7	3.4	5.3
3413	NATAL	5186366.4	-3654225.1	-653022.7	3.4	2.9	3.2	5186348.4	-3654222.4	-653018.9	2.1	2.2	2.7
3414	BRASILIA	4114987.8	-4554148.5	-1732166.1	9.9	8.4	7.9	4114977.8	-4554142.5	-1732154.0	7.7	6.1	7.2
3431	ASUNCION	3093056.1	-4870100.4	-2710045.8	8.5	9.3	12.5	3093045.4	-4870081.7	-2710023.0	7.6	6.5	10.8
3476	PARAMARIBO	3623293.6	-5214213.7	601514.0	3.4	3.3	3.6	3623277.3	-5214210.7	601515.3	2.2	2.0	3.0
3477	BOGOTA	1744649.6	-6114305.6	532205.2	10.4	13.7	9.8	1744650.2	-6114286.7	532208.6	10.2	6.6	9.6
3478	MANAUS	3185785.4	-5514574.5	-347713.2	19.3	35.4	35.8	3185777.0	-5514585.9	-347703.2	18.7	14.5	35.1
3499	QUITO	1280834.0	-6250966.2	-10805.5	3.8	5.9	4.5	1280834.2	-6250955.9	-10800.6	3.6	3.4	4.1
3648	HUNTER AFB	832562.6	-5349553.4	3360596.4	4.1	5.0	5.4	832566.2	-5349540.7	3360585.3	3.6	2.5	3.6
3657	ABERDEEN	1186786.1	-4785205.1	4032892.3	3.4	5.0	4.5	1186787.1	-4785193.1	4032882.3	3.1	3.0	3.0
3661	HOMESTEAD	961766.7	-5679170.6	2729893.8	3.3	3.8	3.7	961767.9	-5679156.6	2729883.5	3.0	2.3	2.6
3902	CHEYENNE	-1234689.4	-4651235.9	4174763.4	28.6	32.1	11.3	-1234700.7	-4651242.8	4174758.6	8.6	6.3	6.3
3903	HERNDON	1088960.0	-4842973.2	3991763.9	12.3	15.5	11.4	1088989.7	-4843005.4	3991776.6	12.1	8.5	8.9
4050	PRETORIA	5051614.8	2726608.6	-2774181.0	4.4	3.8	5.5	5051608.1	2726603.3	-2774166.8	3.2	3.2	4.4
4061	ANTIGUA	2881594.5	-5372540.2	1868034.3	4.2	4.7	5.0	2881592.3	-5372523.9	1868024.4	3.8	3.5	4.3
4081	GRAND TURK	1920409.9	-5619426.1	2319133.4	3.7	5.7	5.0	1920410.9	-5619417.8	2319128.5	3.3	3.6	4.0
4082	MERRITT ISLAND	910567.9	-5539130.2	3017974.0	2.9	3.8	3.7	910567.2	-5539113.2	3017965.3	2.6	2.4	2.8
4280	VANDENBERG AFB	-2671083.7	-4521217.3	3607495.0	4.3	4.4	4.8	-2671073.8	-4521210.5	3607490.4	3.8	3.3	3.6
4740	BERMUDA	2308088.6	-4874314.8	3393092.0	3.8	5.4	5.1	2308087.3	-4874298.2	3393082.1	3.3	3.1	3.8
5001	HERNDON	1088074.4	-4842954.9	3991857.8	4.9	10.2	7.9	1088049.4	-4842948.7	3991840.2	3.6	3.0	3.7
5201	MOSES LAKE	-2127810.4	-3785912.3	4656011.9	2.7	2.8	3.7	-2127802.2	-3785911.5	4656012.1	2.3	2.2	2.4
5410	MIDWAY ISLANDS	-5618764.5	-258231.5	2997243.8	2.9	3.2	4.1	-5618754.1	-258237.5	2997250.2	2.3	2.8	3.6
5648	FORT STEWART	794687.3	-5360063.7	3353093.5	4.2	5.0	5.5	794691.0	-5360051.1	3353082.4	3.6	2.5	3.6
5712	PARAMARIBO	3623307.1	-5214190.5	601672.3	3.4	3.3	3.6	3623289.8	-5214188.0	601673.2	2.1	2.0	2.9
5713	TERCEIRA	4433654.4	-2268159.2	3971673.1	2.7	2.8	3.8	4433637.8	-2268153.2	3971656.8	2.0	2.2	2.5

Table 14 (cont'd)

STATION		SOLUTION WN-12						SOLUTION WN-14					
NO	NAME	U	V	W	σ_u	σ_v	σ_w	U	V	W	σ_u	σ_v	σ_w
5715	DAKAR	5884479.9	-1853580.1	1612763.0	2.3	2.5	3.1	5884468.8	-1853580.1	1612760.1	1.6	2.0	2.3
5717	FORT LAMY	6023416.1	1617949.5	1331651.2	2.7	2.8	3.3	6023410.7	1617946.5	1331655.8	2.0	2.0	2.7
5720	ADDIS ABABA	4900750.1	3968255.1	966340.3	2.7	2.9	3.4	4900749.1	3968253.0	966354.7	2.0	2.1	2.9
5721	MASHHAD	2604406.6	4444124.9	3750345.7	2.6	2.8	3.5	2604404.8	4444122.3	3750344.3	2.1	2.1	2.7
5722	DIEGO GARCIA	1905122.3	6032294.5	-810776.4	4.2	5.5	4.8	1905127.0	6032287.5	-810716.2	3.5	4.1	4.3
5723	CHIANG MAI	-941713.7	5967448.6	2039317.5	3.1	3.3	4.1	-941709.4	5967445.0	2039322.9	2.5	2.3	3.5
5726	ZAMBOANGA	-3361953.2	5365045.5	763623.6	3.0	3.3	3.8	-3361946.8	5365837.0	763627.8	2.3	2.2	3.2
5730	WAKE ISLAND	-5858583.8	1394474.9	2093844.7	2.8	3.1	3.8	-5858574.6	1394467.2	2093847.4	2.1	2.5	3.1
5732	PAGO PAGO	-6099984.0	-997345.6	-1568577.0	5.7	4.4	4.9	-6099970.5	-997355.3	-1568570.9	3.6	3.5	4.1
5733	CHRISTMAS ISLAND	-5885350.8	-2448375.3	221663.1	4.4	3.5	4.6	-5885333.9	-2448380.4	221670.7	2.7	2.9	3.9
5734	SHEMYA	-3851808.1	396416.1	5051343.3	3.2	3.7	4.9	-3851799.0	396409.3	5051342.0	2.7	3.3	3.9
5735	NATAL	5186368.5	-3654226.0	-653022.6	3.3	2.8	3.1	5186350.6	-3654223.7	-653018.9	2.0	2.1	2.5
5736	ASCENSION ISLAND	6118355.5	-1571763.1	-878558.4	3.3	2.9	3.3	6118340.3	-1571761.9	-878553.6	2.3	2.2	2.7
5739	TERCEIRA	4433646.0	-2268192.2	3971663.3	2.7	2.8	3.8	4433629.3	-2268186.2	3971647.0	2.0	2.2	2.5
5744	CATANIA	4896444.1	1316129.4	3856628.4	2.4	2.8	3.2	4896437.7	1316125.0	3856626.2	1.8	2.2	2.3
5907	WORTHINGTON	-449391.6	-4600910.6	4380315.4	5.8	13.8	13.5	-449417.5	-4600905.5	4380288.1	4.2	3.2	4.5
5911	BERMUDA	2308010.4	-4873778.3	3394476.1	3.6	4.9	5.2	2307991.2	-4873773.2	3394463.4	2.6	2.3	3.0
5912	PANAMA	1142664.4	-6196104.1	988340.8	4.8	9.1	7.0	1142644.5	-6196109.1	988336.6	3.1	3.4	4.1
5914	PUERTO RICO	2349423.9	-5576023.2	2010340.5	13.5	21.1	9.7	2349456.9	-5576027.1	2010342.6	10.5	7.0	6.4
5915	AUSTIN	-744066.7	-5465234.3	3192485.8	5.6	15.3	12.8	-744091.1	-5465238.7	3192467.4	3.8	3.8	4.7
5923	CYPRUS	4363335.9	2862258.6	3655380.7	2.5	2.7	2.3	4363332.2	2862254.9	3655380.7	1.9	2.1	2.4
5924	ROTA	5093565.8	-565319.1	3784273.1	2.4	3.1	3.8	5093556.2	-565322.3	3784268.3	1.9	2.6	2.9
5925	ROBERTS FIELD	6237376.8	-1140241.8	687740.0	3.0	3.1	3.6	6237366.3	-1140241.5	687740.2	2.3	2.6	3.0
5930	SINGAPORE	-1542556.4	6186964.6	151827.8	3.3	3.9	4.0	-1542549.4	6186956.7	151833.8	2.6	2.7	3.4
5931	HONG KONG	-2423919.1	5388254.8	2394863.9	3.1	3.5	4.3	-2423914.9	5388250.3	2394869.2	2.5	2.5	3.6
5933	DARWIN	-4071578.3	4714267.0	-1366533.3	4.3	4.4	4.3	-4071568.4	4714253.3	-1366528.3	3.2	3.2	3.7
5934	MANUS	-5367671.7	3437061.4	-225419.4	3.6	3.5	3.8	-5367663.1	3437869.9	-225416.0	2.5	2.5	3.3
5935	GUAM	-5059832.6	3591194.2	1472759.4	2.9	3.0	3.4	-5059825.7	3591186.0	1472762.5	2.1	2.2	2.8
5937	PALAU	-4433470.5	4512939.3	809955.3	3.1	3.2	3.7	-4433463.6	4512930.3	809958.7	2.2	2.2	3.2
5938	GUADALCANAL	-5915106.0	2146873.2	-1037912.8	4.4	3.9	4.0	-5915096.5	2146860.0	-1037909.5	3.0	3.0	3.5
5941	MAUI	-5467771.9	-2381242.7	2254024.0	3.5	3.2	4.4	-5467757.3	-2381246.7	2254033.8	2.5	2.8	3.8
6001	THULE	546566.4	-1389993.6	6180242.4	2.7	2.7	4.4	546568.7	-1389993.7	6180236.7	2.6	2.4	3.4
6002	BELTSVILLE	1130762.7	-4830837.6	3994709.9	2.2	2.7	3.1	1130764.9	-4830831.9	3994704.0	2.0	1.7	1.9
6003	MOSES LAKE	-2127839.9	-3785864.2	4656037.4	2.5	2.7	3.5	-2127832.1	-3785863.0	4656037.2	2.1	2.0	2.3
6004	SHEMYA	-3851806.8	396416.1	5051341.7	3.2	3.7	5.0	-3851797.5	396409.4	5051340.5	2.7	3.3	3.9
6006	TROMSO	2102930.3	721674.1	5958181.7	2.7	3.3	4.4	2102927.4	721668.5	5958180.8	2.4	2.9	2.9
6007	TERCEIRA	4433653.3	-2268156.9	3971671.0	2.7	2.7	3.8	4433637.3	-2268151.4	3971655.0	2.0	2.2	2.5
6008	PARAMARIBO	3623257.3	-5214236.7	601534.8	3.4	3.3	3.6	3623241.0	-5214233.7	601536.1	2.1	2.0	2.9
6009	QUITO	1280834.0	-6250966.2	-10805.5	3.8	5.9	4.5	1280834.2	-6250955.9	-10800.6	3.6	3.4	4.1
6011	MAUI	-5466039.2	-2404429.3	2242224.6	4.4	3.4	3.9	-5466018.6	-2404431.5	2242224.4	3.0	2.9	3.3

Table 14 (cont'd)

STATION NO	STATION NAME	SOLUTION WN-12 U	SOLUTION WN-12 V	SOLUTION WN-12 W	σ_u	σ_v	σ_w	SOLUTION WN-14 U	SOLUTION WN-14 V	SOLUTION WN-14 W	σ_u	σ_v	σ_w
6012	WAKE ISLAND I	-5858578.8	1394516.4	2093817.4	2.9	3.2	3.8	-5858569.3	1394508.7	2093820.3	2.1	2.6	3.2
6013	KANOYA	-3565901.4	4120723.2	3303426.9	4.0	5.2	5.9	-3565892.8	4120713.6	3303428.3	3.3	4.4	4.9
6015	MASHHAD	2604355.4	4444169.2	3750321.7	2.6	2.9	3.5	2604353.3	4444166.0	3750320.5	2.1	2.2	2.6
6016	CATANIA	4896394.6	1316176.2	3856670.7	2.4	2.8	3.2	4896388.3	1316172.1	3856668.2	1.8	2.2	2.2
6019	VILLA DOLORES	2280630.7	-4914547.7	-3355417.9	2.7	3.6	5.2	2280627.1	-4914543.2	-3355402.8	2.4	2.7	3.7
6020	EASTER ISLAND	-1888621.5	-5354098.4	-2895762.3	6.0	6.1	6.9	-1888614.3	-5354094.4	-2895749.0	5.4	4.5	5.5
6022	TUTUILA	-6099975.9	-997357.7	-1568593.6	4.8	3.9	5.2	-6099961.7	-997362.2	-1568585.5	3.4	3.6	4.7
6023	THURSDAY ISLAND	-4955391.2	3842255.7	-1163855.5	4.5	3.9	4.7	-4955386.8	3842247.8	-1163847.4	3.2	3.0	4.0
6031	INVERCARGILL	-4313830.4	891340.6	-4597277.7	4.4	4.2	5.3	-4313825.3	891333.9	-4597265.8	3.4	3.9	3.8
6032	CAVERSHAM	-2375426.0	4875557.6	-3345424.5	3.7	4.3	5.0	-2375420.6	4875546.7	-3345411.1	3.3	3.2	3.9
6038	SOCURRO ISLAND	-2160989.6	-5642717.9	2035368.0	2.9	3.8	4.4	-2160980.9	-5642710.5	2035367.8	2.5	2.8	3.8
6039	PITCAIRN ISLAND	-3724775.0	-4421234.4	-2686094.4	7.9	7.2	7.3	-3724765.9	-4421237.6	-2686084.7	6.2	5.4	5.5
6040	COCOS ISLAND	-741986.1	6190803.6	-1338557.1	4.7	4.8	4.7	-741981.7	6190792.9	-1338546.3	4.5	3.7	4.2
6042	ADDIS ABABA	4900752.0	3968255.1	966318.9	2.7	2.9	3.4	4900750.7	3968252.7	966325.3	2.0	2.1	2.9
6043	CERRO SOMBRERO	1371376.5	-3614750.6	-5055947.1	3.5	4.2	7.0	1371375.9	-3614750.3	-5055927.8	3.3	3.8	4.8
6044	HEARD ISLAND	1098898.5	3684617.0	-5071900.1	6.9	6.7	11.1	1098897.9	3684606.6	-5071873.1	6.8	6.2	7.8
6045	MAURITIUS	3223434.7	5045343.6	-2191818.0	3.6	4.0	4.6	3223432.0	5045336.3	-2191805.7	3.2	3.1	3.9
6047	ZAMBOANGA	-3361983.5	5365820.6	763620.5	3.1	3.4	3.8	-3361976.9	5365811.9	763624.7	2.4	2.3	3.2
6050	PALMER STATION	1192679.3	-2451013.2	-5747052.4	5.0	6.3	9.8	1192678.8	-2451015.6	-5747034.2	4.9	6.1	6.1
6051	MAWSON STATION	1111337.1	2169270.2	-5874355.2	5.0	4.2	7.3	1111336.1	2169262.7	-5874334.1	4.9	3.7	4.4
6052	WILKES STATION	-902611.4	2409530.0	-5816569.9	4.6	4.4	7.4	-902608.8	2409522.1	-5816551.8	4.4	4.0	5.4
6053	MCMURDO STATION	-1310854.8	311262.9	-6213294.3	4.8	4.8	7.4	-1310852.3	311257.5	-6213276.5	4.6	4.5	4.3
6055	ASCENSION ISLAND	6118349.3	-1571749.2	-878601.3	3.3	2.9	3.4	6118334.2	-1571740.3	-878596.5	2.3	2.3	2.8
6059	CHRISTMAS ISLAND	-5885350.2	-2448374.4	221663.6	4.3	3.4	4.5	-5885333.5	-2448379.0	221671.1	2.7	2.9	3.8
6060	CULGOORA	-4751655.0	2792065.7	-3200174.2	4.5	4.0	4.7	-4751650.0	2792058.1	-3200164.0	3.3	3.3	3.7
6061	SOUTH GEORGIA IS.	2999921.2	-2219366.3	-5155267.1	3.9	5.9	7.8	2999915.6	-2219369.3	-5155246.0	3.7	5.7	5.3
6063	DAKAR	5884479.3	-1853496.4	1612858.7	2.4	2.6	3.2	5884467.4	-1853495.0	1612855.1	1.7	2.1	2.5
6064	FORT LAMY	6023394.4	1617934.2	1331731.7	3.3	3.1	3.7	6023386.7	1617931.9	1331733.2	2.7	2.6	3.2
6065	HOHENPEISSENBERG	4213570.2	820033.7	4702786.5	2.6	3.0	3.6	4213564.6	820030.0	4702784.4	2.0	2.4	2.3
6066	WAKE ISLAND II	-5858580.7	1394474.0	2093843.0	2.9	3.2	3.8	-5858571.2	1394466.4	2093846.0	2.1	2.6	3.2
6067	NATAL	5186415.0	-3653935.9	-654280.7	3.3	2.8	3.1	5186397.1	-3653933.3	-654276.9	2.1	2.2	2.6
6068	JOHANNESBURG	5084837.1	2670346.5	-2768109.3	4.2	3.5	5.3	5084830.4	2670341.2	-2768095.2	3.0	2.9	4.2
6069	TRISTAN DA CUNHA	4978430.9	-1086871.1	-3823187.7	8.3	6.6	10.4	4978421.7	-1086874.0	-3823167.8	6.5	6.4	8.1
6072	CHIANG MAI	-941707.8	5967462.5	2039307.4	5.9	5.1	4.9	-941702.1	5967455.1	2039311.6	5.7	4.0	4.3
6073	DIEGO GARCIA	1905134.3	6032292.0	-810742.3	3.7	4.8	4.7	1905134.1	6032282.4	-810732.7	3.4	3.7	4.2
6075	MAHE	3602824.5	5238248.2	-515957.7	4.2	4.6	4.5	3602820.6	5238240.7	-515948.3	3.8	3.6	4.0
6078	PORT VILA	-5952307.7	1231910.5	-1925983.7	19.9	9.4	16.6	-5952303.4	1231904.9	-1925972.5	9.7	8.0	12.4
6111	WRIGHTWOOD I	-2448862.8	-4667992.3	3582759.4	3.0	3.2	3.8	-2448853.3	-4667985.8	3582754.9	2.6	2.1	2.4
6123	POINT BARROW	-1881807.4	-812435.3	6019599.3	4.9	4.6	7.1	-1881799.4	-812439.0	6019590.7	4.6	4.4	4.5
6134	WRIGHTWOOD II	-2448916.5	-4668082.4	3582454.1	3.0	3.2	3.8	-2448907.0	-4668075.9	3582449.6	2.6	2.1	2.4

Table 14 (cont'd)

STATION		SOLUTION WN-12						SOLUTION WN-14					
NO	NAME	U	V	W	σ_u	σ_v	σ_w	U	V	W	σ_u	σ_v	σ_w
7036	EDINBURG	-828491.0	-5657406.5	2816825.5	3.8	3.9	4.0	-828487.0	-5657471.3	2816016.0	3.5	2.4	2.9
7037	COLUMBIA	-191294.0	-4967300.3	3983264.5	3.2	3.5	3.9	-191291.0	-4967293.9	3983252.6	2.9	2.2	2.4
7039	BERMUDA	2308214.8	-4873614.8	3394560.4	3.7	5.3	5.0	2308213.4	-4873598.3	3394558.5	3.3	3.1	3.6
7040	SAN JUAN	2465050.9	-5534945.5	1985522.2	4.0	4.4	4.7	2465049.5	-5534930.0	1985513.1	3.7	3.2	4.0
7043	GREENBELT	1130706.5	-4831337.2	3994141.4	2.2	2.7	3.1	1130708.6	-4831331.3	3994135.5	2.0	1.7	1.9
7045	DENVER	-1240475.1	-4760256.0	4048997.8	4.6	4.2	4.7	-1240470.2	-4760242.1	4048985.3	4.2	2.8	2.9
7072	JUPITER	976261.3	-5601416.4	2880251.4	2.5	3.3	3.3	976261.3	-5601399.9	2880241.9	2.2	1.8	2.3
7075	SUDBURY	692618.7	-4347090.4	4600487.7	4.0	5.7	5.4	692620.7	-4347076.5	4600475.4	3.7	3.8	3.4
7076	KINGSTON	1384159.2	-5905680.0	1966554.4	4.3	5.8	5.9	1384158.7	-5905662.0	1966545.7	4.1	4.4	5.3
8009	WIPPOLDER	3923429.9	299866.1	5003013.3	13.3	13.1	15.2	3923397.4	299869.4	5002975.5	8.5	10.1	6.9
8010	ZIMMERWALD	4331312.7	567499.7	4633118.9	7.9	10.9	11.5	4331307.0	567490.8	4633108.3	5.7	8.3	5.4
8011	MALVERN	3920108.9	-134806.7	5012776.2	12.8	16.5	15.5	3920153.5	-134804.5	5012734.8	8.9	14.3	6.9
8015	HAUTE PROVENCE	4578328.1	457945.6	4403204.8	6.4	10.7	10.2	4578322.1	457936.5	4403195.3	4.2	8.0	4.4
8019	NICE	4579469.1	586582.7	4386428.4	6.3	10.6	10.1	4579463.2	586573.5	4386419.2	4.1	7.9	4.3
8030	MEUDON	4205629.1	163695.4	4776550.9	9.0	12.3	11.8	4205626.9	163683.4	4776540.6	6.5	9.7	5.8
9001	ORGAN PASS	-1535755.1	-5167026.6	3401047.1	4.6	3.9	3.8	-1535750.7	-5167014.4	3401039.4	4.2	2.8	2.7
9002	OLIFANTSFONTEIN	5056115.1	2716514.0	-2775782.9	4.2	3.6	5.3	5056108.4	2716508.7	-2775768.8	3.0	3.0	4.2
9004	SAN FERNANDO	5105589.8	-555269.7	3769680.6	6.3	12.9	8.5	5105581.5	-555271.5	3769676.0	3.4	10.0	4.0
9005	TOKYO	-3946751.4	3366303.2	3698830.3	11.2	10.3	9.8	-3946730.5	3366286.1	3698822.9	9.2	9.0	7.5
9006	NAINI TAL	1018153.3	5471119.3	3109622.2	14.2	10.9	9.6	1018164.5	5471108.7	3109625.6	12.4	5.5	6.0
9007	AREQUIPA	1942762.4	-5804101.6	-1796905.8	2.8	4.0	5.3	1942760.9	-5804088.2	-1796900.9	2.5	2.9	4.4
9008	SHIRAZ	3376872.6	4403990.0	3136250.1	8.1	10.3	9.5	3376875.2	4403976.2	3136257.3	6.8	6.1	6.1
9009	CURACAO	2251813.5	-5816933.6	1327169.7	2.8	3.5	3.8	2251810.7	-5816917.6	1327163.4	2.4	2.1	3.4
9010	JUPITER	976276.2	-5601418.9	2880244.0	2.5	3.3	3.3	976276.2	-5601402.2	2880234.5	2.1	1.8	2.3
9011	VILLA DOLORES	2280578.9	-4914584.8	-3355398.0	2.7	3.6	5.3	2280575.3	-4914500.2	-3355383.7	2.4	2.7	3.7
9012	MAUI	-5466088.5	-2404310.5	2242188.7	4.5	3.4	3.9	-5466067.8	-2404312.7	2242180.4	3.0	2.9	3.3
9021	MOUNT HOPKINS	-1936799.1	-5077719.4	3331926.1	7.3	6.8	6.4	-1936789.3	-5077714.7	3331922.7	7.1	5.3	5.3
9028	ADDIS ABABA	4903727.7	3965208.6	963853.2	2.8	2.9	3.4	4903726.6	3965206.3	963859.6	2.1	2.1	2.9
9029	NATAL	5186459.3	-3653074.6	-654317.9	3.4	2.9	3.2	5186441.4	-3653071.9	-654314.1	2.1	2.2	2.7
9031	COMODORO R'DAVIA	1693795.5	-4112354.3	-4556644.1	8.4	9.4	14.3	1693797.3	-4112353.1	-4556622.0	8.3	8.8	11.2
9051	ATHENS	4606866.7	2029708.0	3903567.4	6.0	12.6	8.9	4606861.5	2029692.2	3903562.2	4.2	10.3	4.4
9091	DIONYSOS	4595164.1	2039433.4	3912675.8	6.0	12.6	8.9	4595158.9	2039417.6	3912670.6	4.2	10.3	4.4
9424	COLD LAKE	-1264834.5	-3466912.6	5105449.2	5.2	6.5	7.7	-1264831.9	-3466915.4	5105450.9	4.7	5.5	4.3
9425	EDWARDS AFB	-2450022.2	-4624438.2	3635041.1	3.1	3.2	3.8	-2450012.7	-4624431.6	3635036.6	2.6	2.2	2.4
9426	HARESTUA	3121262.6	592607.0	5512720.9	9.6	11.4	15.5	3121261.3	592605.7	5512723.0	8.6	9.4	5.8
9427	JOHNSTON ISLAND	-6007458.1	-1111834.2	1825730.0	10.9	20.6	8.8	-6007428.7	-1111852.5	1825733.9	8.9	19.8	8.6
9431	RIGA	3183891.2	1421439.3	5322819.8	13.1	11.7	14.7	3183897.6	1421426.7	5322814.7	12.3	9.4	7.0
9432	UZHGOROD	3907423.8	1602394.2	4763932.7	10.2	12.6	13.7	3907419.2	1602378.6	4763922.1	7.9	10.4	5.9

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3. ACTIVITIES RELATED TO EOPAP.
(Grant No. NGR 36-008-204)

3.1 Earth Physics Application

3.11 Proposed Parametric Evaluation of Earth-Moon System

The main purpose of this research is to combine earth to earth and earth to moon observations to determine the parameters of a non-rigid dynamic Earth + Moon System.

3.111 The Observations Systems

Specifically, the environment for this investigation will consist of the following types of observations:

a) Earth to Moon Laser Ranging. Lunar laser ranging currently in operation affords a very precise earth-moon distance measurement. Two independent reports have investigated the simulated use of lunar ranges for positioning [3] and geophysical [4] purposes.

b) Earth to Satellite (e.g., LAGEOS) Laser Ranging. The proposed launching of LAGEOS under EOPAP [2] would be utilized to simulate ranges as an excellent, precise and repeatable environment.

c) VLBI Observations. A modification of the simulation [3] with the inclusion of Earth/Moon differential interferometry [1] would be utilized to provide precise distances and orientations with Apollo Lunar Surface Experiments Packages, ALSEP's.

3.112 The Parameter System

The proposed research is being conducted to develop an exhaustive model in respect to the following parameters:

Polar Motion (incl. rotation)

Earth-Tides

Variations in Station Coordinates

3.113 References:

[1] Counselman, C. C., Hinteregger, H. F., and Shapiro, I. I., (1972). Astronomical Applications of Differential Interferometry. Science, Vol. 178 (pp. 607-608).

[2] Earth and Ocean Physics Application Program EOPAP. Vol. II, (1973) NASA, Washington, D. C.

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3.12 The Altitude of LAGEOS

3.121 The Satellite and Its Altitude

In the near future a satellite LAGEOS (Laser Geodetic Satellite) will be launched to enable accurate range measurements for both geometric and orbital-mode determinations of positions on the earth.

Ideas of launching a very dense spherical satellite (reduced effects of atmospheric drag and solar photon pressure) existed as early as 1964.

A seminar on Solid-Earth and Ocean Physics at Williamstown, Massachusetts, in August, 1969 suggested that satellite techniques (orbit accuracies of 10 cm) should be applied to the measurement of crustal motions, both on a global scale and in active fault zones.

SAO designed a 76 cm diameter, 3600 kg satellite named Cannonball and submitted the proposal to NASA in 1970.

The redesigned and renamed (LAGEOS) satellite is retained in EOPAP:

Shape	sphere
Radius	22 cm
Mass	680 kg

Mass-to-area ratio	4470 kg m^{-2}
Exterior surface	aluminum
Material	U^{238}
Nodal period	166±2 min
Inclination	$90° \pm 1°$
Eccentricity	0.020 ± 0.015
Altitude	3700 km (?)

SAO also performed comprehensive studies of the influence of various satellite parameters on the range measurements [Final Report on Grant NGR 09-015-164].

Because of the still open question of the altitude of LAGEOS a review will be given of the positive and negative aspects of low and high altitude orbits:

-the orbital altitude should be high enough to reduce to an acceptable level orbit errors resulting from uncertainties in geopotential models

-the orbital altitude should be low enough to provide good signal-to-noise ratios with a retro-reflector array of reasonable dimensions

-all perturbations except the gravitational one can be reduced by increasing the mass-to-area ratio, which suggests lowering the orbit altitude to allow more satellite weight

-the return-signal strength is strongly attenuated by increasing range (R^{-4}), which implies that the orbital altitude should not be any higher than necessary

-the rate at which information is generated usually increases as the mean motion - and therefore the number of passes per day - increases, which suggests a lower altitude

-the satellite must be visible from all observing sites of interest. If we assume a maximum zenith angle of 75° and that about 50 global sites might be occupied during the course of EOPAP, the average separation of adjacent sites would be just under 30° (great circle), suggesting minimum altitude of about 3000 km.

-three forces that significantly influence satellite trajectories are gravity, atmospheric drag and photon pressure. Orbital errors arising from gravity and drag can be reduced by increasing satellite altitude Errors arising from photon pressure can be reduced by increasing the mass-to-area ratio

-the orbital altitude must be adjusted in order to avoid, as much as possible, all resonances with the geopotential. We must surpress perturbations that have periods commensurate with the earth's rotation. Consequently, we should avoid satellite altitudes that result in mean motions of exactly n or n+1/2 revolutions per day etc.

-orbit perturbations caused by geopotential structure are attenuated by increasing satellite altitude: the effects of short-wave length features in the geopotential fall off more rapidly with altitude than do those of long-wave length terms.

The 5 cm accuracy requirement cannot be met for the proposed LAGEOS orbit without improvement in the accuracy of current gravity field models.

As part of EOPAP, geopotential orbit errors for LAGEOS will be reduced to the required levels for orbits at altitudes 3700 km or higher.

-with the proposed orbit a midlatitude station will have an average of six passes with 20° or higher elevation angles each day, with northbound and southbound (satellite motion) passes, with passes both to the east and to the west of the station, and with a variety of elevation angles. This variation in pass-geometry will significantly reduce the influence or orbital errors.

-orbital errors caused by earthshine can be reduced by increasing the orbital altitude. However, a large altitude increase would be needed to effect a significant reduction.

Table 3.1-1
Alternative LAGEOS orbits and payload weights for the TAT(9C)/Delta/TE 364 launch vehicle in polar orbits.

Orbit (rev/sidereal day)	Orbit altitude (km)	Payload weight (kg)	Relative magnitudes of orbit perturbations: Direct solar	Earthshine
8.55	3720	680	1.0	1.0
7.55	4600	600	2.9	1.9
6.55	5690	500	9.3	3.8
5.55	7100	440	33	7.9
4.55	9000	390	120	14.8
3.55	11800	320	600	32

3.122 The Measurements

Mainly two methods of laser range measurements to satellites are available:

A. Simultaneous range measurements (geometric mode)

In this method at least four stations measure simultaneously ranges to a satellite.

A large drawback of simultaneous measurements is the requirement of simultaneous good weather conditions at the four stations.

The geometric mode will still be included in our discussion because it represents the most ideal situation in which station coordinates can be determined by laser range measurements.

By inspecting this method we will at least obtain the upper limit for the accuracy of the station coordinates, not obtainable by any other mode except from simultaneous observations from five or more stations.

B. Short-arc measurements (orbital mode)

Short arc methods are more feasible because of the absence of simultaneous good weather requirements.

Despite its more realistic value this method has a disadvantage because the model is not only described by parameters as station and satellite positions (the latter ones can be eliminated), but has also a large number of additional parameters.

In cases of the short arc methods these extra parameters are mainly the potential coefficients of the earth's gravity field and the orbital parameters.

Due to uncertainty of these additional parameters we expect to obtain lower accuracies for the station coordinates than those obtained by simultaneous laser range measurements.

3.123 Geometric Accuracy Obtainable from Simultaneous Range Measurements to Satellites

The following discussion is based on the paper by L. Aardoom, presented to the Third International Symposium on the Use of Artificial Satellites for Geodesy, April 1971, Washington, D. C.

A prime interest is the variance/covariance matrix of the interstation distances. Restricting to four-station figurations one obvious model is considered: three stations arranged as an equilateral spherical triangle around a central station (see Fig. 3.1-1).

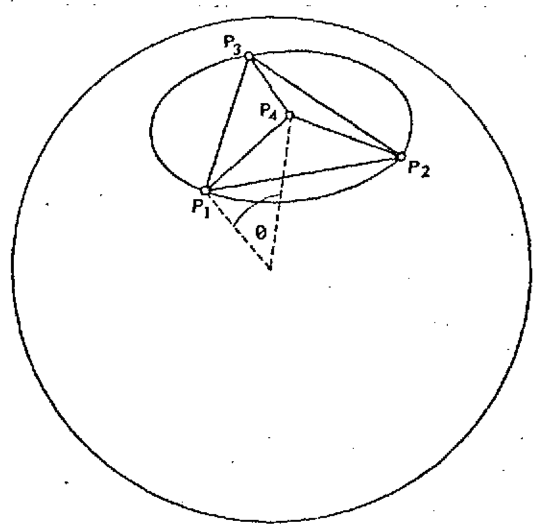


Fig. 3.1-1

Obvious Model Station Configuration (θ is geocentric angle).

Basically, two variance models for the range measurements have been considered:

Case A: The variance of the range measurement depends on the range (l) itself, thus

$$\sigma_l^2 = l^2 \sigma^2 \qquad \sigma^2 = \text{constant}$$

Perhaps not an unreasonable model due to range uncertainties originating in the influence of the troposhpere on propagation velocity.

Case B. The variance of the range measurement is not dependent of the range, thus

$$\sigma_l^2 = \text{constant}$$

This is the more accepted model today.

Case A

$$\sigma_l = l.\sigma \rightarrow \sigma = \sigma_l / l = \sigma_{\ln l}$$

Consider the ratio M

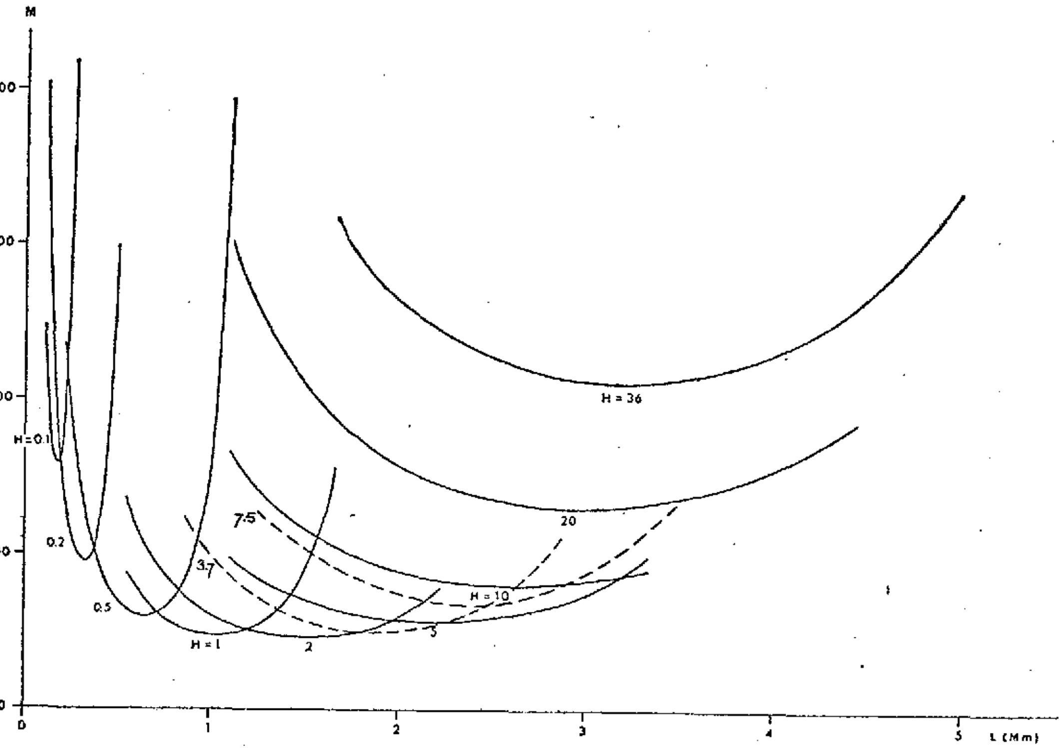
$$M = \left\{ \frac{\text{var } (\ln L)}{\text{var } (\ln l)} \right\}^{\frac{1}{2}} = \frac{\sigma_L}{\sigma_l}$$

where L= interstation distance

l= station-to-satellite distance

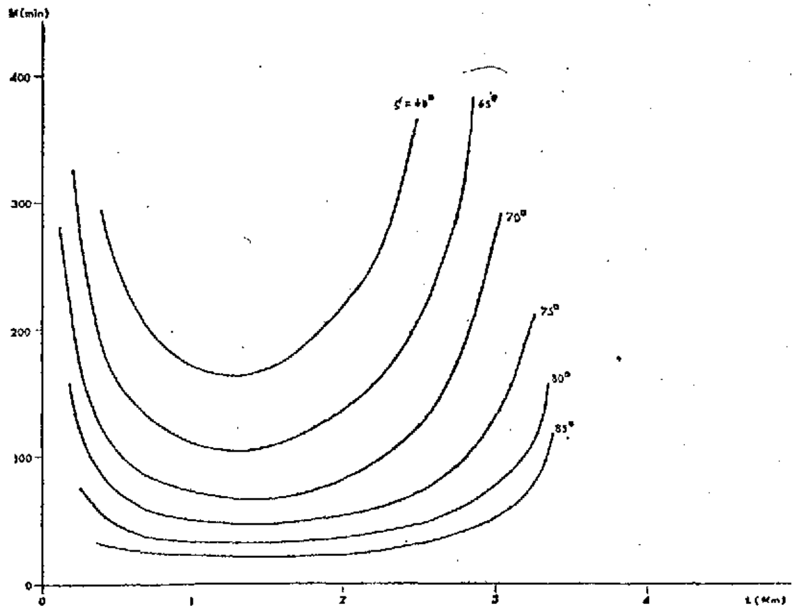
From figure 3.1-2 it can be easily seen that for the model $\sigma_l = l.\sigma$ an altitude of about 2000 km yields the smallest proportional standard deviation M, provided that the stations are about 1550 km apart (maximum zenith distance = 75°).

The next figure (3.1-3) suggests that something can be gained by increasing the maximum zenith angle. Especially in the range of 60° to 75° a substantial improvement can be obtained.



Largest proportional standard deviation M of interstation distances for satellite altitudes H from 0.1 to 36 megameters and maximum zenith distance $\zeta = 75°$. Ground distance L is given in megameters. M is based on unit proportional ranging variance.

Fig. 3.1-2



Minimum values M(min) of standard deviation M of interstation distances for maximum zenith distances ζ between 60° and 85°. L is given in megameters. M(min) is based on unit proportional ranging variance.

Fig. 3.1-3

From these figures ($\zeta = 75°$) for the LAGEOS case the following numbers can be interpolated:

Altitude (H)	Optimum Interstation distance (L)	Proportional Standard Deviation (M)
3700 km	1850 km	50 X
7500	2500	70

From the shape of the curves in Fig. 3.1-2 it is easy to see that at low satellite altitudes the optimum interstation distance is more critical. For example, in the low altitude case increasing or decreasing the intersta-stion distance by 1000 km from the optimum distance the accuracy decreases by 150% while in the higher satellite case by only 55%. On the other hand the higher satellite is 40% less accurate even when the optimum interstation distances are maintained.

Case B

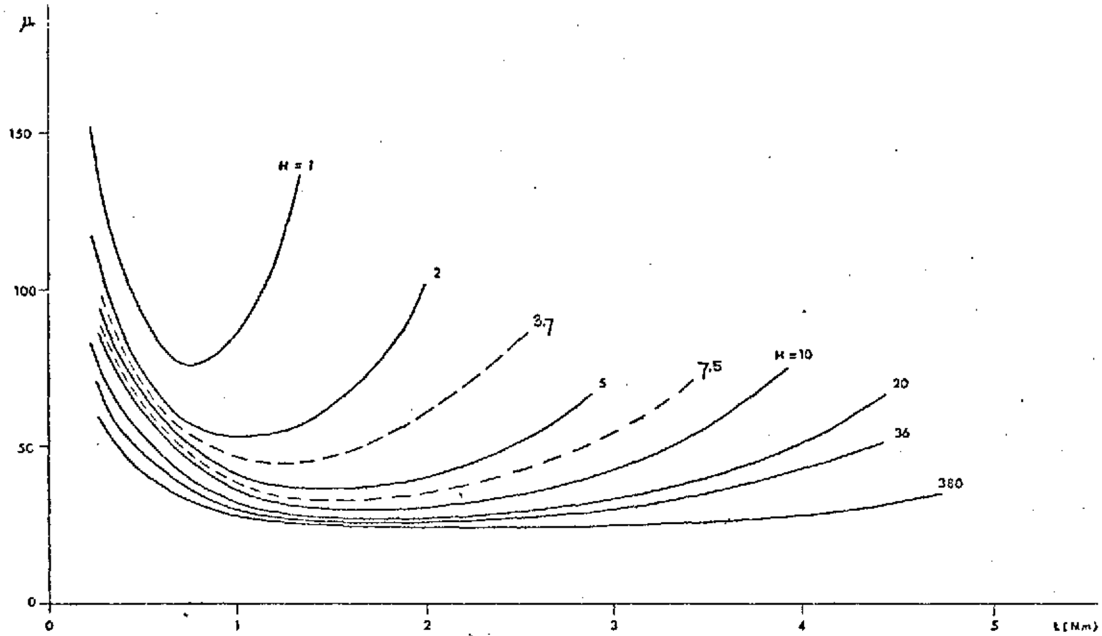
In this case σ_1 = constant, and Figure 3.1-4 applies. The general shape of the curves immediately reveal that higher altitudes are more preferable. In the figure

$$\mu = \frac{\sigma_L}{\sigma_1}$$

Interpolation gives the following numbers for LAGEOS:

Altitude (H)	Optimum Interstation distance (L)	Proportional Standard Deviation (μ)
3700 km	1250 km	45 X
7500	1500	35

Decreasing the optimum distances by 500 km the accuracy for the lower satellite decreases by about 25%, for the higher altitude by 15%. The higher satellite is 22% more accurate when the optimum interstation distances are maintained. Increasing the optimum distances with reasonable amounts is not critical.



Largest standard deviation μ of interstation distances for satellite altitudes H between 1 and 380 megameters and maximum zenith distance $\zeta = 75°$. L is given in megameters and μ is based on unit ranging variance.

Fig. 3.1-4

Conclusions: In Case B higher is the satellite less sensitive is the solution to the interstation distances. If the lower proposed altitude of LAGEOS is to be the standard for optimum interstation distance, the range of such distances for the higher altitude will have to be limited approximately to 800-2700 km. This accuracy is about 45 X the accuracy of range observations for a single ranging from the four stations. Thus if 200 observations are made with 2 cm accuracy, the expected interstation distance accuracy is $45 \times 2/\sqrt{200} = 6.4$ cm, provided that for the lower satellite the interstation distance is 1250 km, and for the higher one it is between 800-2700 km. Outside this range the accuracy will decrease.

In Case A the accuracy obtainable with the optimum interstation distance for the lower altitude (M=50 X) can not be reached at all with the higher satellite. The estimated maximum accuracy with the higher satellite is about M = 70 X. This could be reached with an interstation distance of 2500 km. The same (or better, down to M=50 X) accuracy can be reached by the lower altitude for stations 1300-2800 km apart.

3.124 Proposed Investigation of the Geometric Accuracy obtainable in the Short Arc Mode

Realizing that the calculations in section 3.123 are only very approximate and they don't reflect practical considerations, an attempt will be made to pin down an optimum altitude for the short arc mode.

The investigation will consist of two parts:

A. Geometric Effects

The optimum altitude will be determined by the position of the observing station with respect to the orbital plane:

-Unfavorable case: Satellite goes through zenith

Advantage: Many observations

Disadvantage: Weak determination of station perpendicular to orbital plane

-Favorable case: Satellite is at closest approach at a low elevation

Advantage: Strong determination of station coordinates

Disadvantage: Few observations

The optimum between the favorable and unfavorable case will also depend on

1. altitude of satellite H
2. max. zenith angle
3. var/covar. model $\sigma_1 = 1.\sigma$, or $\sigma_1 = \text{const.}$
4. refraction model

B. Physical Effects

The coordinates of the satellite are not strictly known due to the uncertainties in the potential coefficients of the earth's gravity field. Effects (parameters) as drag, solar radiation, initial orbital elements, will also influence the coordinates of the satellite in the short arc.

Another subject will be the investigation of the possibility to recover time dependent station coordinates.

3.2 Ocean Physics Applications

During this reporting period a basic study was conducted to evaluate and discuss the possible contributions of geodesy to ocean physics program of EOPAP. This study is partially based upon earlier publications of Jet Propulsion Laboratory, Battelle Columbus Laboratories and NASA. For obvious logical reasons we have subdivided this study into four parts:

3.21 General remarks and definition
3.22 Problem areas and Accuracies (achieved and desired)
3.23 Solution of problems and conceptual approaches
3.24 Conclusions and recommendations

3.21 General Remarks and Definition

Since over a decade scientists have been involved with precise location of stations in the oceans for obtaining gravimetric, geophysical and oceanographic data. The first published paper, proposing a method for the establishment of such station, is the result of the research done at Lamont Geological Observatory [Ewing, et al. 1959, pp. 7-21]. Ewing called such stations as "Geodetic bench marks at sea", which were established by using the SOFAR sound transmission, by which the high geodetic accuracy could not be achieved. George Mourad [1965, p.5-10] proposed a geodetic method for establishing the ocean-bottom bench marks, by using satellites, EDM - and sonar instrumentation. As sonar instrumentation is the only way for underwater measurements, Mourad introduced a new term "marine geodesy" to differentiate it from the classical geodesy. As we will see later in sections 3.23 and 3.24 that to solve most of the problems, precisely located stations on the ocean-bottom are needed, which could be considered partial or local geodetic nets, thus the term "marine geodesy" appears to be very appropriate. We would define marine geodesy as the science which defines and establishes control-points in and/or on ocean, and the shape of the ocean, including its floor.

3.22 Problem Areas and Accuracies

The problem (application) areas could be classified either according to the physical aspects of the ocean (on the oceanic surface or within oceanic water) or according to the scientific and practical needs. The following scientific problem areas have been partially mentioned in many publications [Anon, 1972b; Kaula, 1969; Loomis, 1972; Mourad and Fubara, 1972]:

a. Topography and Mapping
b. Positioning and Navigation
c. Boundary Demarcation and Determination
d. Sea-level Slope Determination
e. Tsunami Warning System
f. Recovery of Underwater Objects and Equipment
g. Ecology
h. Gravity Measurements at Ocean floor
i. Ground Truth and System Calibration

It is worth mentioning here that our effort will be concentrated on the subsurface (underwater) problems.

a. Topography and Mapping. As the resources of the ocean bottom become more developed, the need for an extensive survey of its topography increases. Projections indicate that by 1980 a third of the oil production - four times the present output of 6.5 millions barrels a day - will come from the oceans [Anon, 1969, p. 85]. Further for laying cables and oil pipe-lines, for emplacing geophysical and geodetic station at the ocean floor, for determining the dump-sites and new land acquisition (similar to Hawaii Experiment to acquire land from the ocean for airport expansion), and for bathymetric navigation a reasonably good knowledge of ocean-bottom topography is necessary. How far are the oceans mapped can be realized from the following statement [Cohen, 1970, p. ix]: "When a student recently requested a government agency to send him "a map of the uncharted areas of the Pacific," he received exactly that--a graphic based on extremely sparse and dated information. It is deplorable and dangerous fact that this situation still exists in vast areas of ocean. For much of the Pacific, the most recent source of information is the United States Exploring Expedition which Lieutenant Charles

Wilkes led in 1838."

b. Positioning and Navigation: Positioning and navigation can be subdivided into the following three categories:

(i) General Navigation (long range). This includes ships and other vehicles on the ocean surface. Its accuracy requirements are most probably met with the existing Navy Navigational Satellite, and in future with the stationary satellites using doppler systems. However, navigational accuracy requirements for certain fishing "boats" is ±45 m; these boats are used up to 300 miles off coast in up to 250 fathom depths [Anon, 1972d]. To achieve such accuracies better navigational systems are required.

(ii) Submersible Navigation (short range). The short range submersibles are used for underwater research, for multipurpose exploitations on the continetal shelf and deep oceans. These small vehicles are usually battery operated, and are brought to the work-area from where they initiate their operation. Their navigation system is limited within 5 mile range with capability of pinpointing their position to ± 1 foot in each of the three dimensions of movements; this ± 1 foot accuracy is with respect to local control.

To achieve this accuracy three basic types of devices are used: sonar doppler system to obtain speed and distance, sector display system for passive target location and general collision warning, and sonar buoys for position fixing. The last system using sonar buoys is of interest to us. The conventional position determination underwater is done by emplacing three transponders on the ocean-bottom, whose known positions along with sonar range data are used to determine the unknown position of the submersible. Details of this system and its drawbacks will be dealt with in section 3.23.

(iii) Submersible Navigation (long-range). To this group belongs the submarines (Polaris i.e., missile and non-missile) and the submarine cargo tankers. The systems used for submarine navigation include 3 SINS (ship's inertial navigation system), Doppler and Loran-C. Due to the lack of precise information regarding submarine navigation, which is a classified area, let us evaluate the accuracies of the above-mentioned systems.

Although SINS is a self-contained system, which needs no external reference, its accuracy is low, caused by an inertial drift of 108 m/hr which is accumulative with respect to time. To update SINS, doppler observations are regularly made by "popping up" the doppler pole antenna over the ocean surface after a few days, and also continuous positioning is done using Loran-C floating antenna, which always remains on the ocean surface. The positional accuracies obtained by doppler (Navy Navigation Satellite) is ± 0.22 n.m, and by Loran-C ± 0.5 miles up to 1000 miles and ± 5-15 miles beyond 1000 miles off coast [Beck, 1971, p. 48-50]. As such the total accuracy of submarine navigation can not be better than ± 0.5 miles (± 800 meter) up to 1000 miles and ± 5-15 miles beyond 1000 miles off the coast.

These accuracy estimates might be satisfactory for long-range submarine navigational requirements so far as they can obtain measurements from Loran-C and doppler. But the problem remains for the following two submarine navigational needs:

1. Submarine navigation under ice-capped oceans, where one has to depend only upon the SIN-systems, which have a drift rate of 2.6 km/day. To update SINS under iced seas, the only possible way is sonar navigation by providing ocean-bottom transponders along the desired route. Such a technique could open an easy and fast way of transporting oil from the North Slope of Alaska.

2. Short range submersible navigation beyond 1000 miles off coast. As the short range submersible is brought to the work-area due to its limited 5 mile range navigation system, their "carriers" - the long-range submersibles - should have their positional accuracy within ± 5 miles when they are beyond 1000 miles. This is however not the case. Thus we require better navigational system at least for those long-range submersibles which cooperate with short-range submersibles.

c. Boundary Demarcation and Determination. The boundary demarcation could be either for national, international or commercial purposes. International boundary limits, which include national limits, for territorial seas and fishing jurisdiction are mostly within 12 n.m from the coastal line, seldom up to 200 n.m [Anon., 1972a, pp. 118-121]. Boundary determination and demarcation up to 12 n.m from the coast can be done by using EDM-Instrumentation. The demarcation in free ocean, such as 200 n.m limits, remains an unsolved problem.

Further continental shelves/slopes and free oceans are being searched for mineral resources and fuel (gas and oil). As the existing port facilities are inadequate for huge oil tankers, plans are to construct super-ports in the ocean far away from the crowded not-deep enough coastal area. Recommended are construction of large nuclear power plants in the ocean for the ocean will serve as the logical coolant [Shoupp, 1973]. All these developments make the ocean very valuable. To accomodate all these groups interested in getting their share of ocean, it should be divided in cells and leases granted to the interested group. Leasing of cells involves legal definition of underwater boundaries and their practical demarcation becomes necessary specially when the lease bid from the oil industry went as high as $27,400 per acre [Anon., 1970a, p. 215]. According to Jones and Smith [Anon., 1970a, p. 219] an accuracy of ± 25 feet is satisfactory for practically all work performed in the deveopment of an offshore oil field. In deep-ocean after 100 miles from the coast this accuracy is not yet available, though perhaps technologically feasible.

Thus the situation remains the same whether the boundary determination is for oil exploration, for superport site or for nuclear power plant site. Due to the high leasing costs the boundaries in the oceans have to be determined accurately up to ± 10 m.

d. Sea-Level Slope Determination. The oceanographic results, on both the Pacific and Atlantic Coasts of the U.S., indicate a slope downward to the north, with the large magnitude on the Atlantic Coast. Whereas U.S. Levelling net adjustment of 1963 indicate a rise in sea-level from south to north, with a slope of 2.8×10^{-7} on both sides [Sturges, 1973, p. 28]. A discrepancy of about 1 m exists between geodetic and oceanic levelling in north-south direction.

If a ± 10 cm accuracy could be achieved in determining the ocean depth at a particular point, i.e., between the ocean surface and the ocean-bottom transponder, the discrepancy between the geodetic and oceanic levelling could be resolved.

Once the three-dimensional position of the ocean-bottom transponders is known, change of water column height with an accuracy of ± 1 mm could be measured by the water-pressure sensor [Loomis, 1972, p. C-15]. Thus the average sea-levels for certain stations on the Pacific and the Atlantic coasts could be determined, from which the comparison of geodetic and oceanic levelling results can be made.

e. Tsunami Warning System. Tsunamis are long sea waves, which are generated by a sudden vertical faulting (shift) of the sea-floor associated either by an earthquake with its hypocenter (focus) beneath the sea bed (Figure 3.2-1) or by a submarine landslide caused by an earthquake with its epicenter possibly on land (Figure 3.2-2).

The abrupt vertical displacement of the sea floor is transmitted to the sea surface as a crest or a trough. The wave then propagates in all directions across the entire ocean basins with a speed, which is a function of water depth, given by $\sqrt{g.h}$, where h = water depth. In the open ocean 1000 meter deep, a tsunami wave will have the speed of 100 m/sec and the wave height is limited to a few meters, normally a few tenths of a meter according to [Bullen, 1963, p. 319-20; Loomis, 1972, p. C-9 to C-10]; and about 30 cm [Zetler, 1972, p. 26-22], but the principal wave-length may be of the order of some hundreds of kilometer, and the principal wave-period

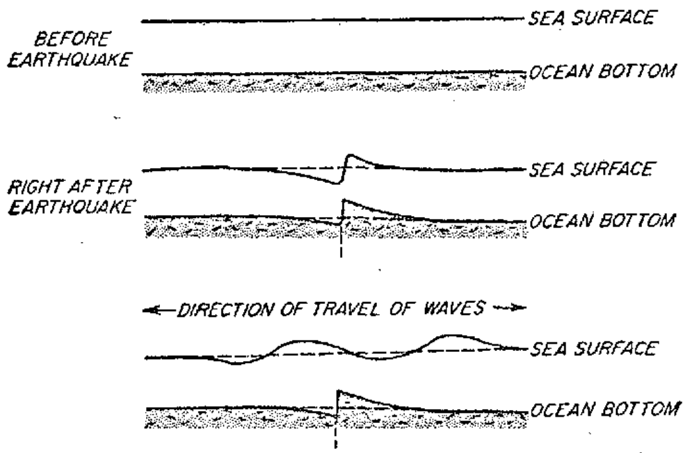


Fig. 3.2-1 Schematic diagram showing the theory of the formation of a tunami by faulting of the sea floor. Waves spread in both directions from the location of the fault. Vertical scale greatly exaggerated.

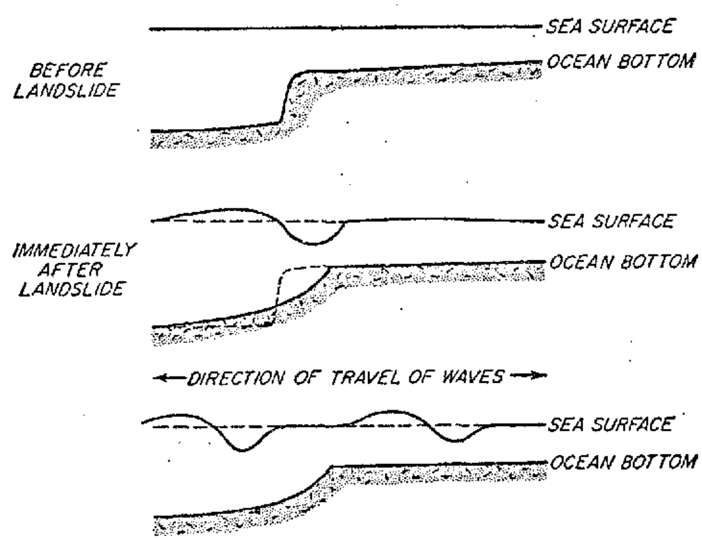


Fig. 3.2-2 Schematic diagram showing the theory of the formation of a tunami by a submarine landslide. Vertical scale greatly exaggerated.

(Figures taken from [Howell, 1959])

of the order of some tens of minutes [Bullen, 1963, p. 319].

As these waves approach the coastal slopes, the wave-length decreases and the amplitude increases, building up to destructive heights. In U- and V- shaped inlets the tsunami wave can reach a height of the order of 20-30 meters with an on-rush speed of above 10m/sec (36 km/hr).

Destructive tsunami waves have been entirely restricted to the Pacific Ocean. They have tended to be generated in approximately 15 specific seismic areas in the approximately 36,000 mile earthquake and volcanic belt circumscribing the Pacific; only about half of these are currently active. However, the active areas are limited to approximately 15,000 miles.

The existing tsunami warning system (Fig. 3.2-3) with headquarters at the NOAA Honolulu Observatory uses an array of 21 seismograph and 41 tide stations around the Pacific. The initial warning of a potential tsunami is the recording at the Honolulu and Tokyo Centers, of an earthquake of 7.0 magnitude or larger within the Pacific area. The location of an epicenter for such an earthquake is usually computed in less than an hour. The tide stations near the epicenter are then asked to report their data and to confirm if a tsunami wave has actually been generated.

After reviewing the seismic and tide-gauge data, and the past histories of the known tsunami origin points and their destruction areas, a decision to issue a tsunami warning is made. For localities near the epicenter warnings may be issued on seismological data only. Two-thirds or more of all tsunamis warnings are false alarms [Loomis, 1972, p. C-11; Zetler, 1972, p. 26-27].

Thus we face three problems:

(i) Our present ability to predict tsunamis is practically unsatisfactory;

(ii) Even after a tsunami has been generated, its energy density and its velocity of propagation in open sea is impossible to predict; and

(iii) The most serious problem is the fact that the propagation velocity of tsunami in shallow areas is strongly affected by the ocean bottom topography and shore line contours, and as a result a substantial portion of energy in a particular tsunami can be focussed on a relatively small segment of the ocean shoreline, where the most destructive effects are experienced.

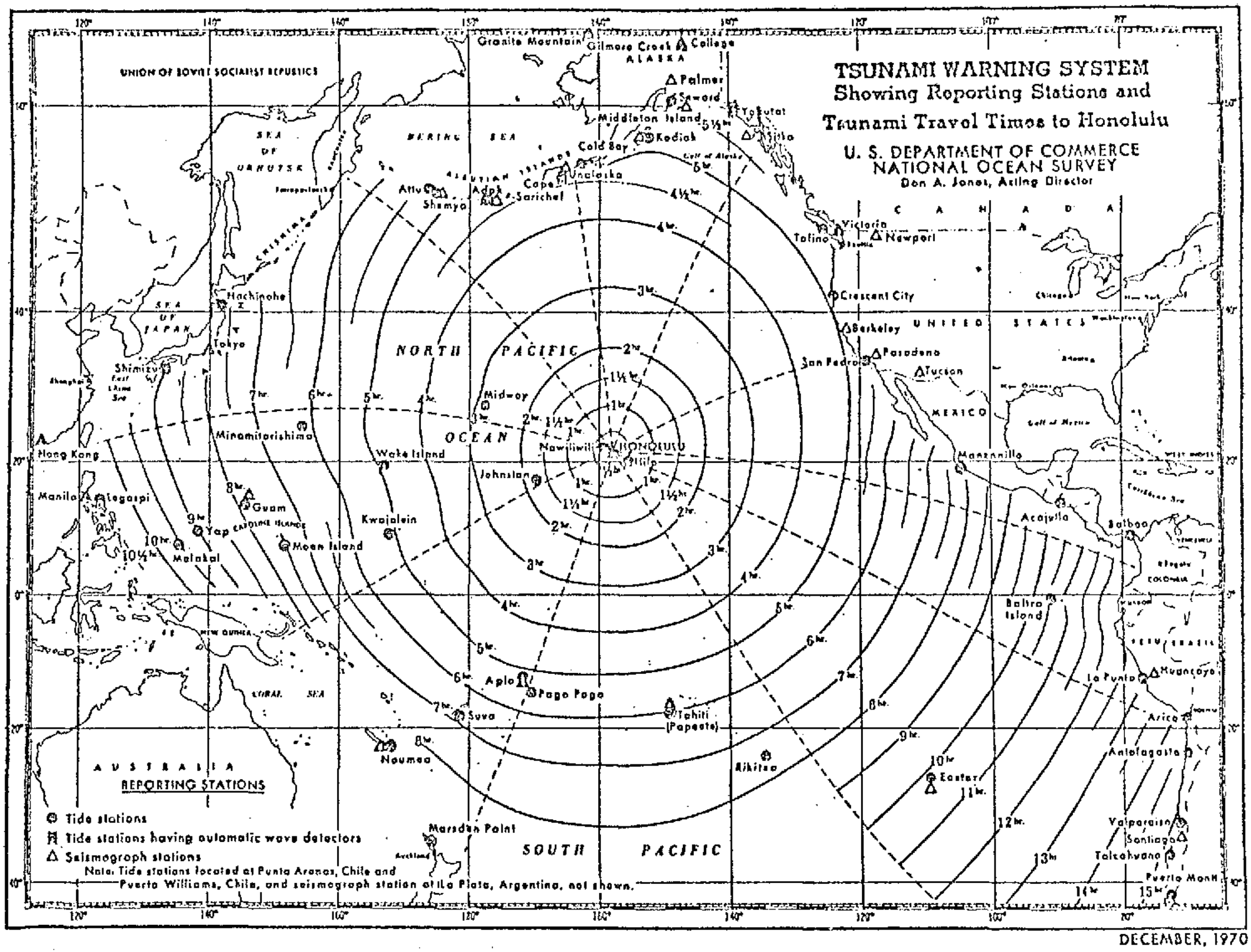


Figure 3.2-3 Tsunami warning system, January 1971.
(Figure from [Zetler, 1972])

f. Recovery of Underwater Objects and Equipments. Scientists working with submerged instrumentation face a basic uncertainty about the recovery of the instrumentation from the ocean. Oceanographers and geophysicists have often mentioned their failure to recover most of their submerged equipment. The fact that the ocean bottom transponder net with 3 transponders-array-configuration is used in the test areas, it appears that either this 3 transponder configuration is not functional, or the geodetic technique is not clear to the users. Whatever may be the reason, the problem to recover the valuable scientific equipment from the ocean remains to be solved.

g. Ecology. . For ecological reasons trend is to dispose of the garbage in the oceans at pre-selected sites. Experiments are being conducted here in America and in Japan for finding a suitable way for ocean waste disposal. The by-products of this ecology experiment are: (i) cities have no more dump site problems, and (ii) acquisition of "new land" from the oceans; such ideas exist to obtain "new land" from the ocean for airport expansion in Hawaii.

The garbage undergoes chemical tests and treatment; before compacting the garbage in rectangular bundles, it should have a well-defined chemical composition and desity. These garbage rectangular packages can then be dumped at pre-selected sites, for which a good knowledge of ocean bottom topography and a good positional accuracy of the dump vehicle (ship/boat) are necessary. Both of these requirements are lacking.

h. Gravity Measurements at Ocean Floor. Gravity work and other geophysical surveys in the oceans could neither be interconnected nor connected to a datum. According to Hendershott [Loomis, 1972, p. C-14] for meaningful results these surveys should be connected to some ocean-bottom control net, which does not yet exist.

i. Ground-truth and System Calibration. It is surprising that the existing instrumentation for measuring water depth in free ocean can not be tested for its claimed accuracy due to non-existing civilian facilities for calibration [Thompson, 1973]. However there exist 5 naval calibration sites [Anon, 1970b, p. 118].

In Table 3.2-1 are shown the accuracy requirements for various tasks as estimated by various studies. In the last column are given our estimated accuracies.

3.23 Solution of Problems and Conceptual Approaches.

The above-mentioned problem areas can be solved by means of (A) a Global Marine Geodetic Control-Net (GMGCN) on the ocean-floor, (B) Advanced Satellite Instrumentation (ASI), and (C) Underwater Sonar Instrumentation (USI).

a. Global Marine Geodetic Control-net (GMGON)

The idea of a global marine geodetic control net (GMGCN) was first mentioned by Ewing and his associates [1959], and later modified by Mourad [1965]. Ewing proposed SOFAR sound transmission to measure distances between two bench-marks where a bench mark was defined as the point on or below the water surface from which the round-trip travel time to all the three ocean-bottom acoustic transponders, placed at the corners of an equilateral triangle, would be equal. Mourad proposed geodetic (electronic distance measuring instruments), acoustic (sonar instrument) and space (satellite instrumentation) techniques. Knowles and Roy [1972] describes a system basically similar to that of Mourad and Fubara [1972] but with 6 ocean-bottom transponders instead of 3 in each array.

The deficiencies of the above-mentioned systems are:

(1) The accuracies given by them are not "realistic", as these ocean-bottom arrays were neither connected to any geodetic coordinate system nor any provision was made for such a connection, which is one of the main objectives of EOPAP.

(2) Although a ship is used to determine the positions of the ocean-bottom transponders, its (ship's) coordinates are considered errorless, which

Table 3.2-1

Positional Accuracies Requirements [in meters]

TASKS	Chart Acc. [Cohen, 1970]	Battelle Study							OSU Estimated Desired Accuracy+
		Desired Absolute			Desired Relative			Achieved	
		φ	λ	h	φ	λ	h		
Navigation:									
General Navigation (L.R.)[1]	± 3000								± 45-500
Submersible* (S.R.)[1]	± 300								± 1 m
Submersible* (L.R.)[1]	± 2000								± 500
Ocean Resources									
Geophysical Surveys (oil expl.)	± 200				± 10-100	± 10-100	± 5		± 15
Drilling	± 25				± 1-5	± 1-5	± 1-5		± 10
Pipelines					± 1-10	± 1-10	--		± 3
Cable laying	± 100				± 1-10	± 1-10	--		± 3 - ± 10
Dredging/Mining	± 25				± 2-10	± 2-10	--		± 2
Geodesy & Ocean Physics									
Control Stations	± 10	± 10	± 10	± 5	± 1	± 1	± 1		± 10
Geoid		--	--	± 0.5	--	--	± 0.1		± 0.1
Calibration Standards		± 10	± 10	± 5	± 1	± 1	± 0.3		± 1
Mean Sea Level					± 50-100	± 50-100	± 0.1		± 0.1
Stationary Buoys Loc.		± 10	± 10	--	± 10	± 10	--		± 0.1
Boundary Demarcation								± 50-300	± 10
-National									± 10
-International									± 10
-Ocean Cadastral									± 10
Ecology	± 250								± 10-50
Search & Rescue	± 25	± 20-100	± 20-100	--	± 1-10	± 1-10	--	± 12-200	± 10-20
Tsunamis									± 0.1

*Excluding Submarines - No Estimate Available
+[Jones and Sheriff, 1969; Putzke, 1969; and Anon., 1972b; Beck, 1971].
(1)L.R.= Long Range; S.R. = Short Range

are either obtained by Navy Navigation Satellite or by airborne techniques (Lorac) to an accuracy of a few dekameters or more (30-100m)[Loomis, 1972, p. IV-6]. Thus the accuracies of transponder positions are derived from in-error ship oositions.

(3) Transponder depths are used in the computations. These are not the measured quantities, but are computed from slant ranges between the ship and the transponders. To be mathematically rigorous, the depth should be measured quantities and due weights should be applied to them.

(4) The mathematical derivations are rigorous in the beginning, but are approximated later, thus introducing modelling error.

The above-mentioned deficiencies can be overcome in the following way:

(1) An ocean-bottom transponder array should consist of 4 transponders instead of the conventional 3 in each array; this will avoid the singularity of the system, and also will be useable if one transponder ceases functioning. However, a study is imperative to find how many transponders are necessary in one ocean-bottom transponder array, specially because Mourad thinks 3 transponders in each array are required and Knowles thinks 6. We have also to think how these trnasponder arrays are placed: before emplacement of these transponders a reasonably large area (25-40 miles squares) of the ocean bottom is mapped using Depth Sounders. Then a smaller flat area proportional to its water depth is selected for transponder arrays. This water depth-flat area ratio limits the array configuration, and hence the number of transponders in each array. For practical reasons the term benchmark should be defined physically as a particular transponder of a particular array and not as a fictitious point as defined by Ewing, et al. [1959] and Mourad [1965].

(2) The number of transponders in each array could be decreased to 3 if somehow the directions between the ocean-bottom transponders and the

ocean-surface transducer could be determined. These directions would provide necessary constraint to the control-net, thus avoiding the singularity and providing a unique solution. A system to measure the directions between two sound sources can be designed with the existing technical knowledge similar to that of Electronic Angles Measurement Systems.

(3) The depths of the transponders should be actually measured, and then compared with the computed depths. The only problem in this is that there are no exactly known depths in the free ocean, which can be used as ground-truth to verify the accuracy of these modern sonar instruments [Thompson, 1973]. The instrument (Innerspace Autotrack Model 404) can measure depths up to 10,000 meters with an accuracy of ±4.36 m. This optimistic accuracy estimate takes into account three sources of error (assuming a constant velocity of sound 4800 ft/sec.): (i) timing accuracy of the oscillator (±0.00 25%) (ii) resolution of the display (± 0.3 m) (iii) reply integrator time constant (.1 to 10 ms).

However the above accuracies are quite small compared to the effect caused by the difference between the actual and assumed velocity of sound. A 10 ft/sec velocity difference will contribute to an error of 2.04%, which is one magnitude larger than the accuracy of the system (0.04%). Thus to obtaine geodetic accuracies, it would be necessary to determine a profile of the sound velocity vs. depth and then to calculate the average velocity at the location of interest.

(4) The transponder arrays should be connected to some geodetic datum, which can be achieved by using an Active Laser Satellite similar to Geole system of DIALOGUE Project [Thieriet, 1972], "floating buoy reflectors" on the ocean surface and ground-based reflectors at known stations. Thus a truly unified global network can be achieved even in the remotest ocean areas.

(5) A rigorous mathematical model is necessary, and the use of the gravity information should be made.

(6) To make the transponder arrays more versatile to be used also as a geophysical station for Tsunami warning, it should consist of a water-pressure sensor and a vertical seismometer, both of these would be on the ocean floor [Loomis, p.C-15]. A study of the essential instrumentation at the ocean-bottom transponder site to enable it a multi-purpose station is necessary, for which discussion with oceanographers, geophysicists and other users are needed.

b. <u>Advanced Satellite Instrumentation</u>

An active laser satellite like Geole system of Dialogue Project could be very useful. The Geole system should obtain accurate positioning of slowly moving points (like buoys) to ±1m over one-day measurements, and to ±10-20m every two hours from one single measurement [Thieriet, 1972]. The satellite will be at 3500 km height and will make the measurments.

c. <u>Underwater Sonar Instruments</u>

As the only form of radiation, which propagates effectively underwater, is sound, it is most important for underwater measurement. The sonar instruments operate on a fixed theoretical sound velocity (4800 ft/ sec), although velocity of sound depends upon the conditions of the water layers (salinity, pressure, temperature) and depth of water. How to calculate the correct velocity at required depth or the average velocity during many water layers has been achieved by determining a profile of the sound velocity vs. depth, and then to calculate the average velocity.

What has not been done and should be done is to verify the accuracies of these instruments, which indirectly will involve verification of the calculated average velocity. There is no calibration range for civil scientific purposes, although five test ranges exist for naval use [Anon., 1970, p. 118].

A comparatively easy development of an acoustic instrument to determine directions between two sound sources is necessary to lessen the number of transponders in each array.

The conceptional approaches mentioned in this section can be summarized as follows:

(1) An active laser satellite around 3500 km high in circular orbit is necessary. Thus the position of floating buoys/ships could be determined within ± 1 to 10 meters, which will further improve the ocean-bottom transponder position. It will also connect the ocean-bottom transponder net to a unified global datum, and demarcate and determine the boundaries (national, international, leasing) in the open ocean to a high accuracy.

(2) Underwater sonar instruments require calibration for which a Civilian Test Range is needed. A new development to determine the direction between the sound sources is necessary so as to lesen the number of transponders in each array.

Just to illustrate how our conceptional approach can be used to solve the problems mentioned in Section 3.22, it will be applied to improve the Tsunami Warning System.

Conceptual Approach for an Improvement in Tsunami Warning System. As mentioned earlier that two-thirds or more of all tsunami warnings are false alarms, the existing Tsunami Warning System needs improvement.

Van Dorn [Loomis, 1972, p. C-12] suggested that stations should be located on the ocean floor (and not on the continental shelves) off the seismically active belt. He suggested a 6 station critical net as follows:

1 station off Japan
2 stations off the Aleutians
2 stations off South America
1 station off the South-western Pacific Island.

Zetler [1972, p. 26-27] mentions that if a tsunami could be detected on the open ocean, it would be very valuable to the warning system. According to Zetler, it does not seem likely that space craft/satellite measurements could be helpful for tsunami detection in open ocean.

It is quite evident that tsunami data from the open ocean is very valuable to improve the existing tsunami warning system; this could be achieved by combining laser and ocean-floor station data.

A system could be designed using the existing technology: At "suitable" locations on the Pacific ocean-floor acoustical transponder arrays could be placed. Each transponder should be equipped with water pressure sensor, vertical seismometer and other essential instrumentation to make it a multi-purpose station. On the ocean surface are placed stabilized platforms (floating buoys) whose bottom is mounted with acoustical transmitter/transponder and upper surface with a laser reflector. The active laser satellite of DIALOGUE type could position these reflectors (slowly moving objects) to ±10 m for one measurement, and ±1 m from one day data; the range accuracy is ±2 m and radial accuracy ±2 mm/sec [Thieriet, 1972].

The sonar data from the ocean-bottom transponder net will provide the relative position of the "floating buoy" in all the three dimensions.

Note that the sonar data will be always available on command; but laser and satellite data will be available only when the satellite is in that region.

Operational Procedure: After the recording of an earthquake of 6.3 magnitude [Iida, 1970, p.3] and consequently locating its epicenter, the ocean-bottom transponders, the surface buoys and the laser satellite will be asked to report their "height difference" data at one minute interval. Thus a complete record of the wave-height and its speed can be computed. This "sonar" height data is measured automatically and with the speed of sound, which is approximately equal to the velocity of P-waves (1.5km/sec) [Bullen, 1963, p. 321]. Whereas the tsunami speed in open ocean of 1000 m depth is only 100 m/sec. Thus the tsunami warning - after reviewing the sonar, laser and seismic data - could be issued more reliably within minutes after the earthquake occurence.

Due to the fact that a harmless tsunami wave of the open ocean may become destructive reaching the shore depends upon the topography of the continental slope and of the continental shelf, a few transponders/floating buoys have to be located in this region.

3.24 Conclusions and Recommendations

We will now summarize the work to be done in marine geodesy:

(a) Accuracies Available and Required. The instrumentation accuracies as given by the manufacturer have to be evaluated. This will require study of investigations done by various users using the instrument under evaluation. After this evaluation it could be decided which instruments should be used for obtaining the specific accuracies.

Also needed is a scientific survey of user's accuracy requirement. This is a very difficult task as most users do not want to discuss their desired accuracies.

(b) Simulated Network Design. A basic simulated network design by using the modern instrumentation is necessary as this is the "back-bone" of the entire operation. For such design one has to consider primarily, the users' requirements, the configuration criteria, and how best a hybrid system can be used.

The important advantage of ocean-bottom transponder net over satellites is that satellites can track for a limited time when they are above a particular station, while ocean-bottom transponders can either track continuously or can be activated on command. This is very important for tsunami warning system.

The network design can be conducted in three stages: (1) Unit Array: Configuration and number of transponders necessary in one array; the type of observations needed; type of instrumentation in each array and/or at each transponder to make it a multi-purpose station; (2) Regional Net: Configuration of transponder arrays in areas of scientific interest and in practical problems areas, like boundary determination; (3) Global Net: Eventually to plan and design a global net based upon scientific regional nets mentioned in (2) above.

The network design in each of the three stages should be connected to a geodetic datum.

(c) Ocean Surface Determination. The existing discrepancy between geodetic and oceanic levelling should be clarified. This could be done by using a regional net in the areas of discrepancies.

(d) General Navigation. Inertial navigation systems, which usually have large drift rates, can be updated with geodetic information. A study in this area, probably supplementing inertial navigation systems with gradiometers, could provide a solution to other specific navigational problems.

(e) Master Plan for Ocean-bottom Network. Looking at certain publications, it becomes clear that some users and scientists have their "own" transponder net on the ocean bottom. It will be worthwhile at least to plan a global network, using the existing scattered transponder nets, if possible.

A master plan should be prepared which should provide information about the transponder types, their locations and working frequencies, obtained data and type of data. This master plan should be similar to the National Geodetic Satellite Program so as to avoid duplication of work.

(f) Cooperation with Battelle. A close scientific cooperation is being attempted with Battelle Columbus Laboratories, which is involved in Ocean physics and marine geodesy. Such a cooperation will be beneficial to the scientific progress.

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4. PERSONNEL

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5. TRAVEL

J. P. Reilly and Tomas Soler
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Attend the Fourth GEOP Conference

Ivan I. Mueller
Washington, D. C., October 11, 1973
Attend EOPAP Conference

Ivan I. Mueller
Sidney, Australia, November 26-30, 1973
Attend the IAG/AAS Symposium on Gravitational Fields and Secular Variations in Position (partial support)

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